COLLINS

Comparison of Reducing Motions for Indicators

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A Comparison of Reducing Motions for Indicators

..BY..

GUY RICHARD COLLINS

THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE IN

MECHANICAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

OF THE

UNIVERSITY OF ILLINOIS

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May 31, 1901 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Guy Richard Collins

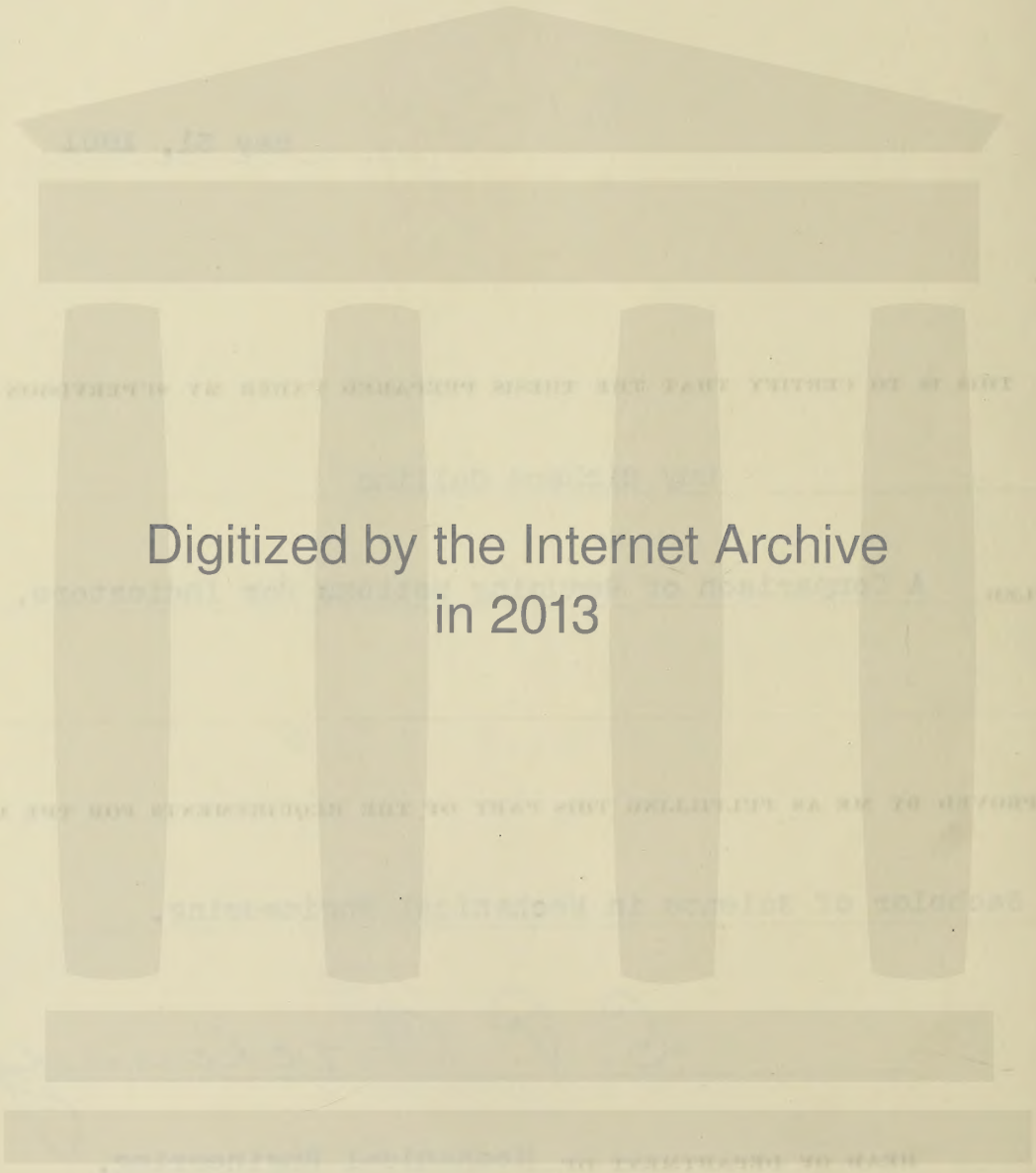
ENTITLED A Comparison of Reducing Motions for Indicators.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering.



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A Comparison of Reducing Motions for Indicators

The object of the investigation described in the following pages, is to determine the relative accuracy of several types of reducing motions. This has been done first, (Kinematic treatment, by tracing an approximately correct motion, and one which is known to be perfectly correct, and later, test of the results thus obtained, have been checked up, by actual experiments, on an engine. The proportions of the mechanisms have been changed, and the effect on the accuracy of the motion by so doing, has been noted.

On pages 4, 5, 6, 7, are shown diagrammatically, several different types of motion reducing devices. The types shown in figures 1, 2, are, accurate, and require no special investigation. That shown in figure 3, is approximately accurate. I have investigated this, quite carefully, and the results will be seen further on. Figure 4, shows one type, from which we might expect to get accurate results. It will be seen that the only error introduced by this motion, is that due to angularity of string, which is so very small, that it may easily

be [illegible] in ordinary cases.

Figure 5 shows a mechanism that gives an approximate reversing motion. The swinging link makes it applicable when the crosshead of an engine is surrounded by material in such a way as to render the other types useless. Figure 6 shows also an approximate reversing motion which is little used on account of its great inaccuracy. Figure 7 shows the same as shown in figure 3, except that the sector is introduced to keep the strap in guides. The type shown in figure 8 is analogous to that in figure 4, with the sector added. In figure 8 we have an accurate type of reversing motion. The motion in figure 9 is the same as that in figure 3 with the short arm added. This arm is for the purpose of giving the strap travel in a line other than parallel to the line of travel of the crosshead. The same change is made in figure 4 to produce that shown in figure 10. The motion shown in figure 11 is [illegible] from that of figure 5 in a similar manner. Figure 12 shows another accurate type. Figures 13 & 14 show two more

approximate & accurate types. Figures 15 & 16 show methods of reversing sometimes used on locomotives. The motion shown in figure 15 is accurate. and that shown in figure 16 is approximately so.

It is seen that some of the types are very much alike in their construction. As it stand. we see 5 perfectly accurate motions and [illegible] motion. Now if angularity of string be disregarded we will have eight accurate reducing motions. and eight approximate motions. The angularity of string in the ordinary case produces [illegible] variance from the true centre line of the valve-facing in the indicator was but .18 inches there was found to be an error of a fourth one half of one per cent. These conditions would hardly ever happen in ordinary practice.

[illegible] that we could expect just about the same degree of accuracy from the motions in figures 3, 7, & 11 we will place them in a class to themselves. As shown in figures 9 & 11 form a second class. [illegible] figure 6 forms a class by itself and those shown in figures 13 & 16 form a fourth class. I have selected a motion from each class. from them have derived [illegible] of this discussion.

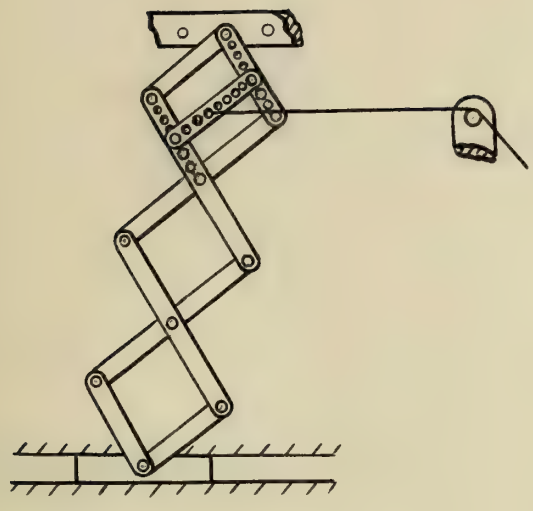


FIG. 1.

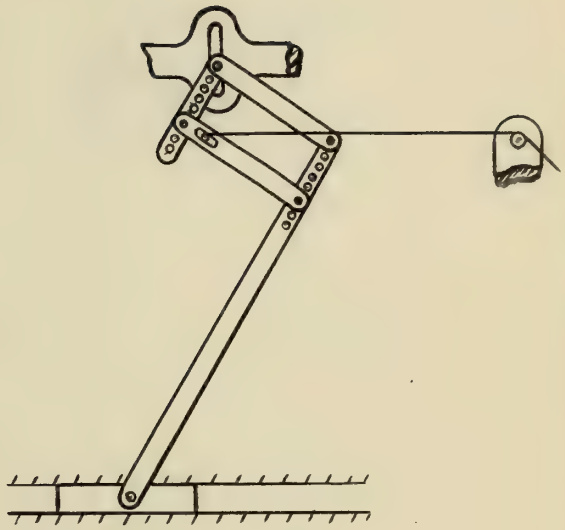
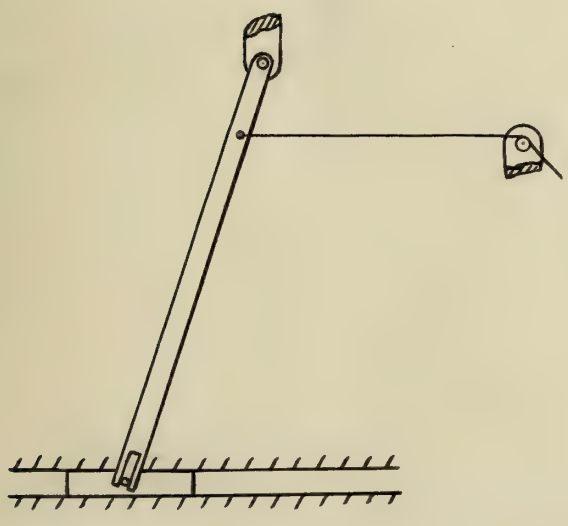


FIG. 2.

FIG. 3.



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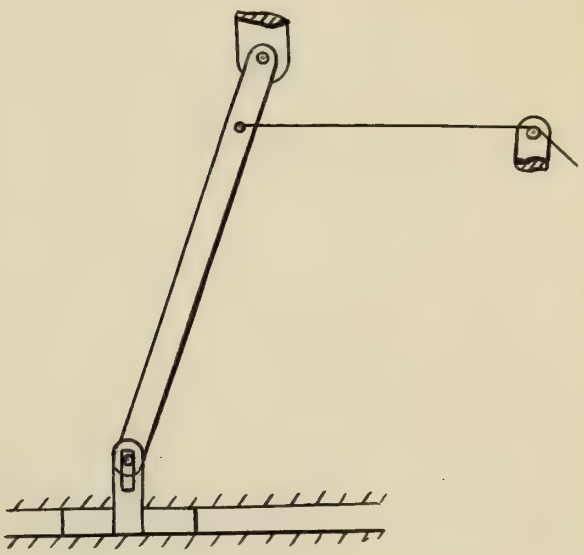


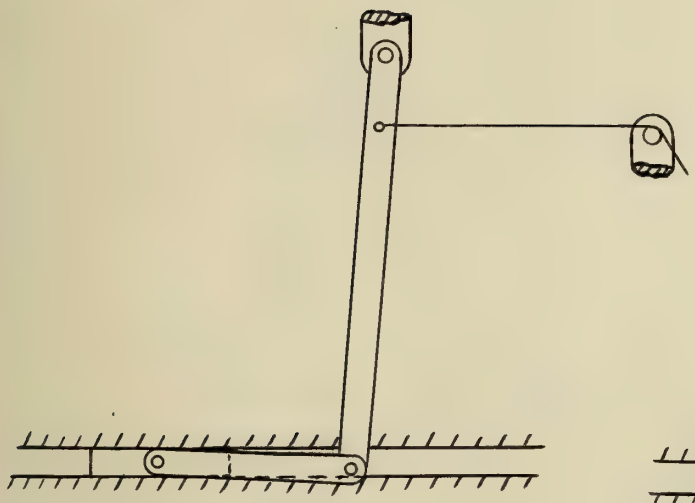


FIG. 5.

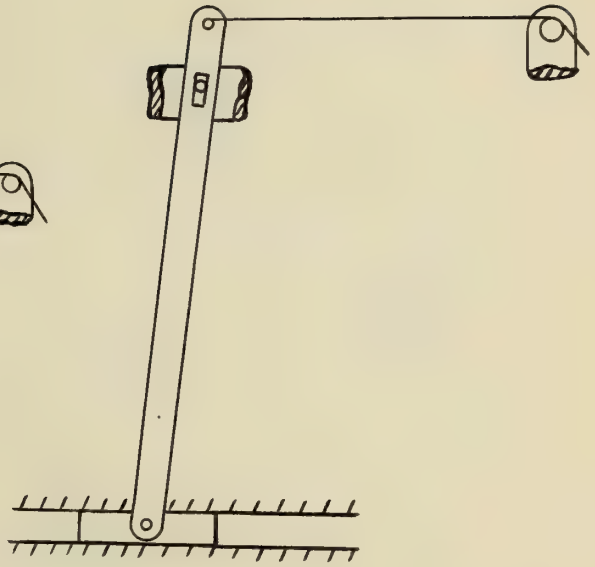


FIG. 6.

FIG. 7.

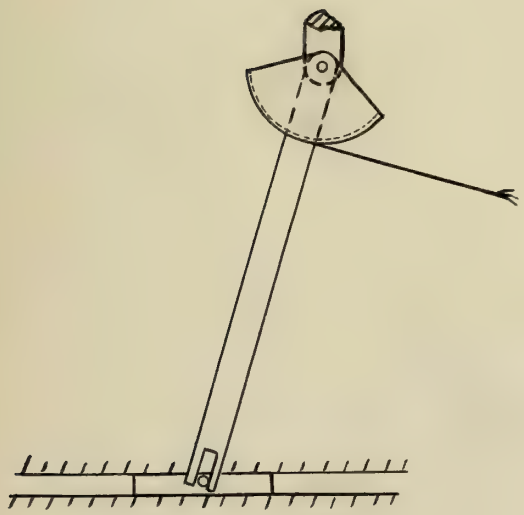
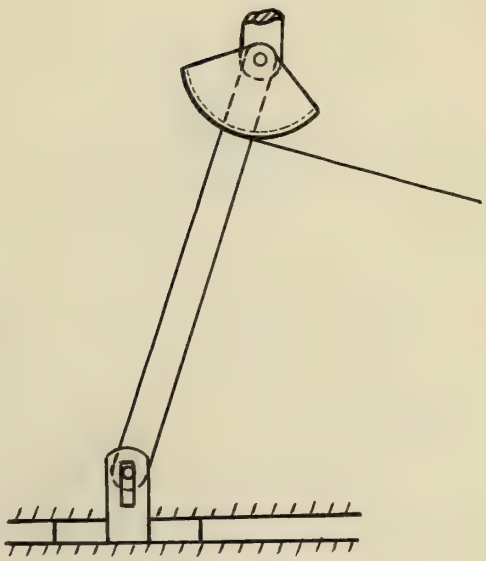


FIG. 8.



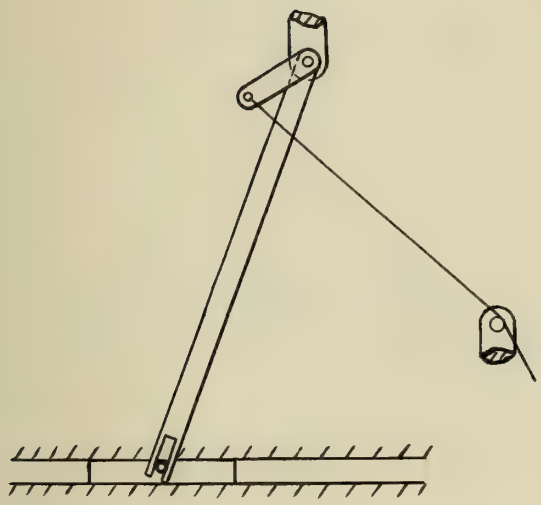


FIG. 9.

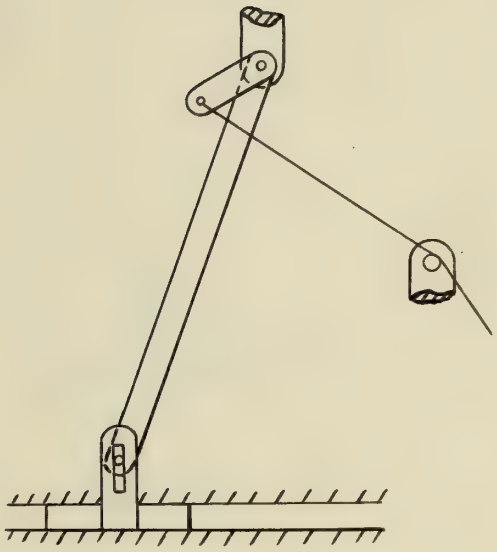


FIG. 10.

FIG. 11.

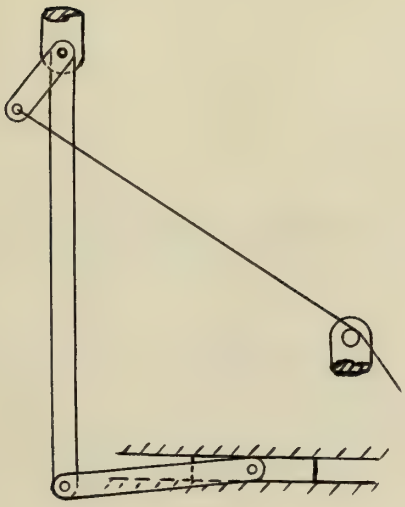
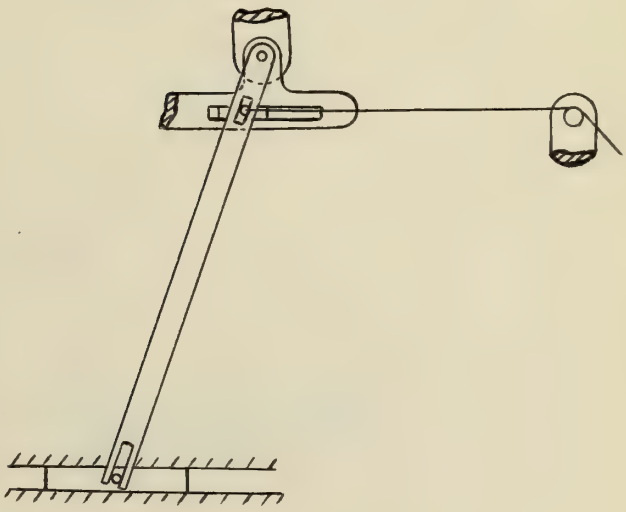


FIG. 12.



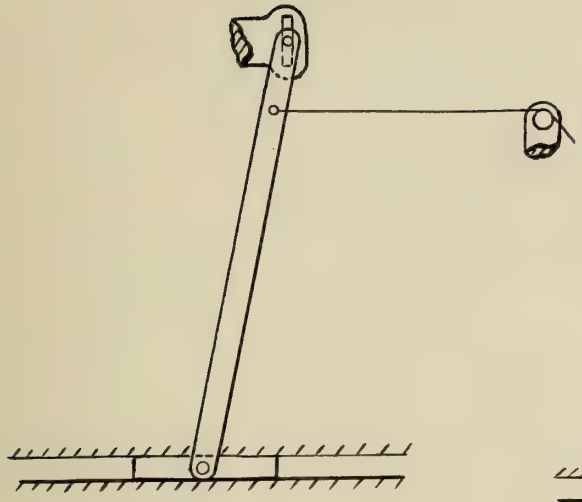


FIG. 13.

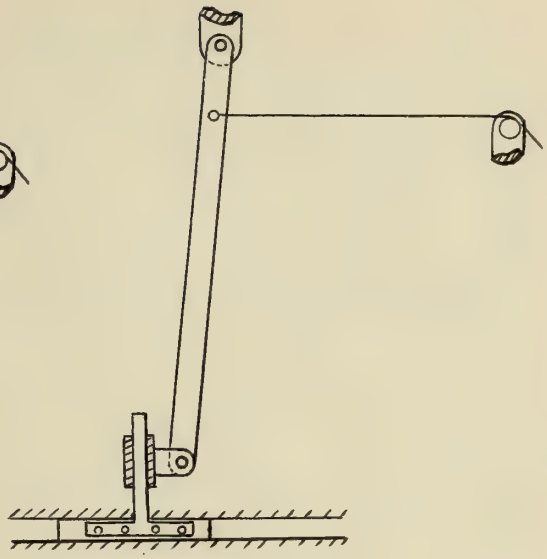


FIG. 14.

FIG. 15.

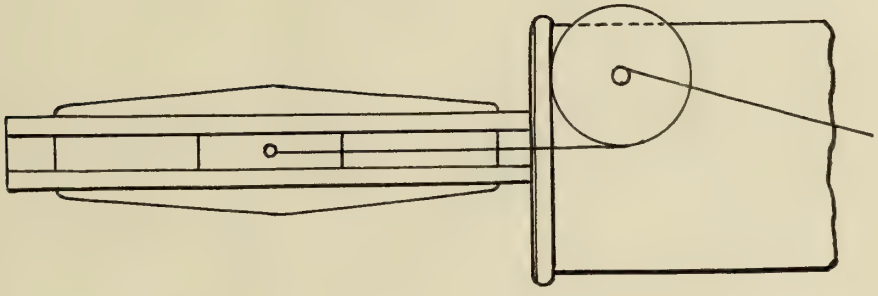
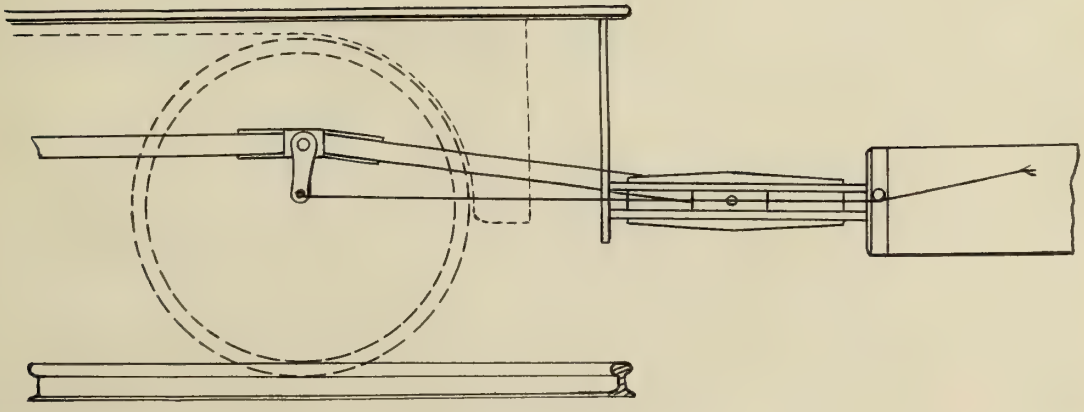


FIG. 16.



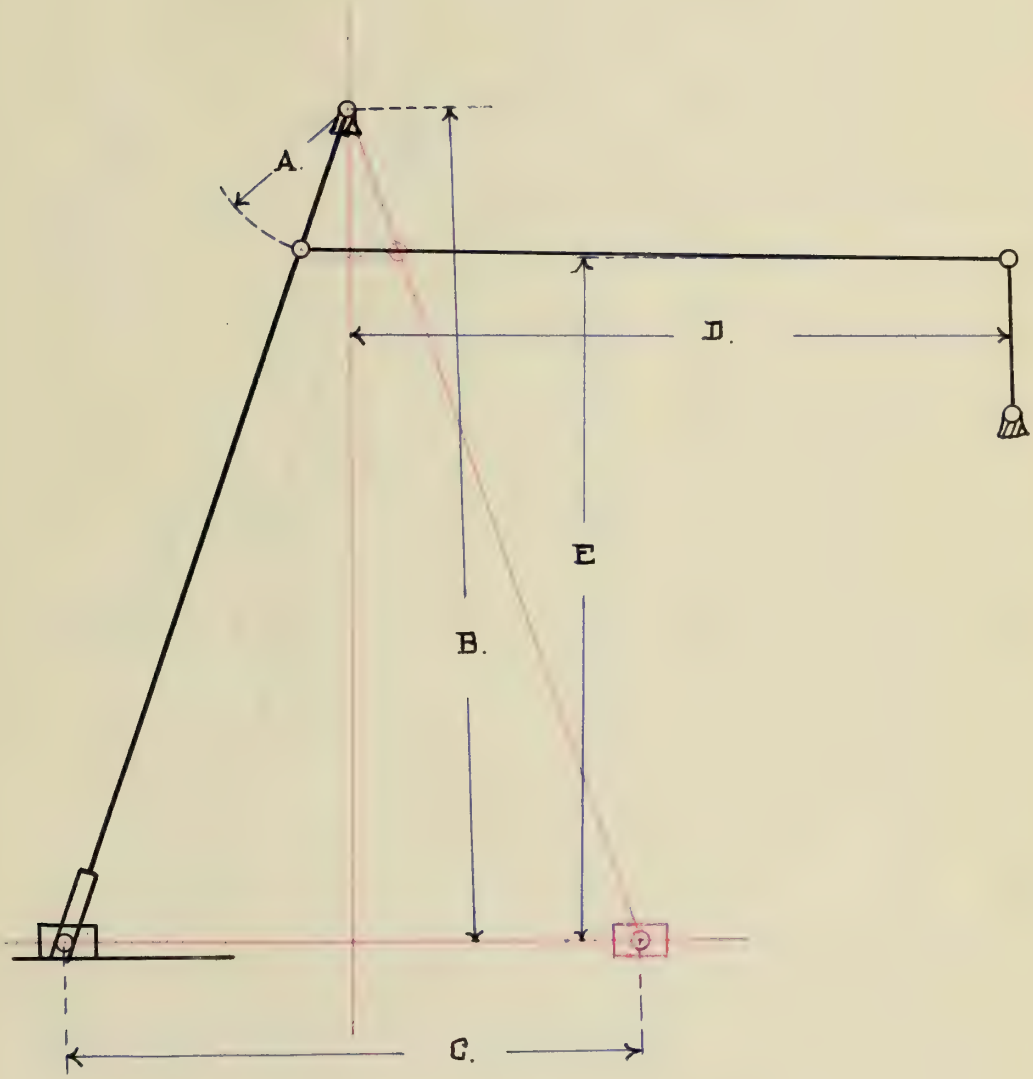
The first type of reducing motion investigated is that shown in figure 3. On page 11 is a diagrammatic sketch showing the dimensions which are usually employed in rigging. I have assumed three cases. In no. 1 the usual dimensions are used. In the other two the length of arm is made longer and shorter respectively than is commonly employed. The stroke is taken the same in each case as is also the length of rod, the stroke being 24 inches, and the rod being 48 inches in length.

The method of solution is the polygon. The solution is effected more quickly and accurately in most cases by this method than by the usual analytic method. By referring to page 1 the method of solving this particular case can be readily seen. On page 2 are given velocity curves and on page 3 the corresponding displacement curves. Looking at the velocity curves we see that the ratio first falls below 1:6 to a minimum of .92:6 for case one, .9:6 for case two, and .98:6 for case three at the beginning of the stroke. At one fourth stroke the ratios are each 1:6. At mid stroke they are 1.03:6 for

case one 1.024:6 for case two. and 1.12:6 for case three. At three fourths stroke the velocity ratio's are the same as at one fourth stroke. and at the end they are the same as at the beginning. We see that a point on the string then had a tendency to lag behind on the start. At one fourth stroke it begins to catch up, and so continues up to one half stroke. It then begins to decrease in velocity in the same rate that it increased up to one half stroke.

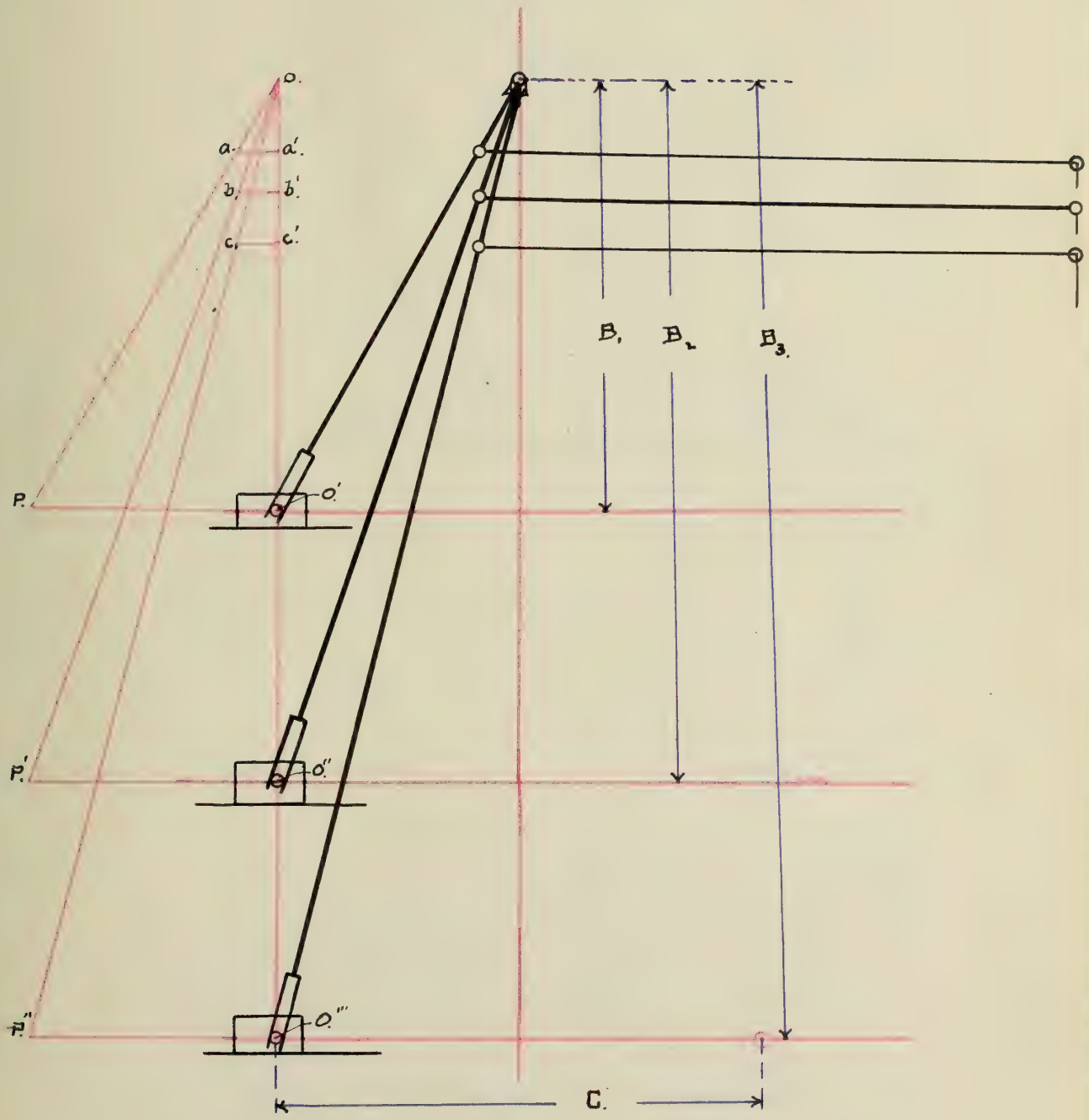
Let us now refer to the displacement curves on the next page. It is seen that they fall below the constant displacement line on the start, and cross it at the middle of the stroke. At one eighth and one fourth stroke. the displacements fall below what they should be. At one fourth stroke the displacement in case one is .912 inches. .952 in case two and .972 in case three. At one half stroke the displacements are two inches as they should be. A thing to be noticed in regard to the curves, is that the velocity curves are the first derivatives of displacement curves. Where the velocity curves are a maximum the

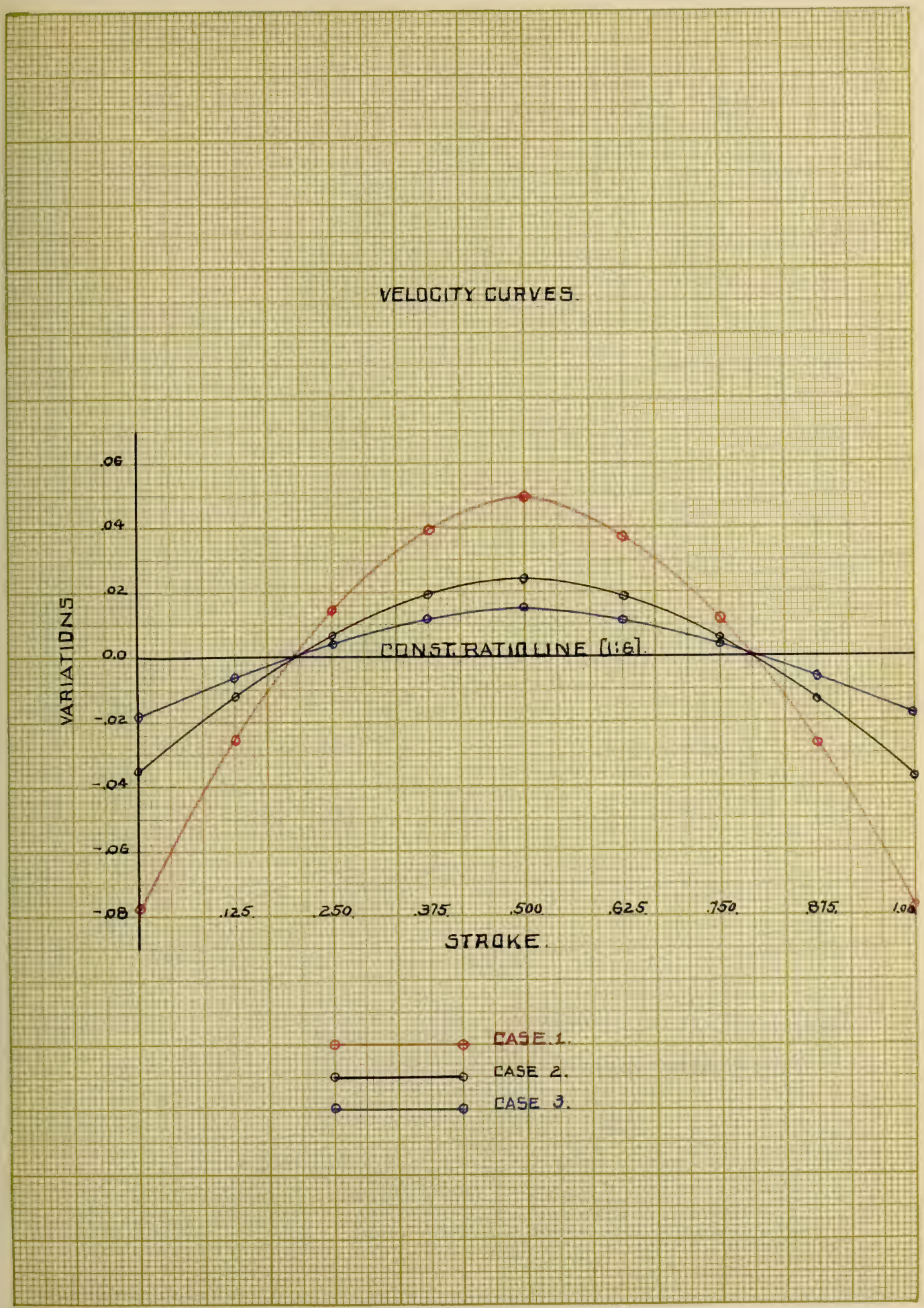
A. = 6."
B. = 35."
C. = 24."
D. = 28."
E. = 29.2."



THREE CASES.

$B_1 = 23.3''$ (1).
$B_2 = 35''$ (2).
$B_3 = 46.6''$ (3).
$C = 24''$
LENGTH OF CARD = 4".





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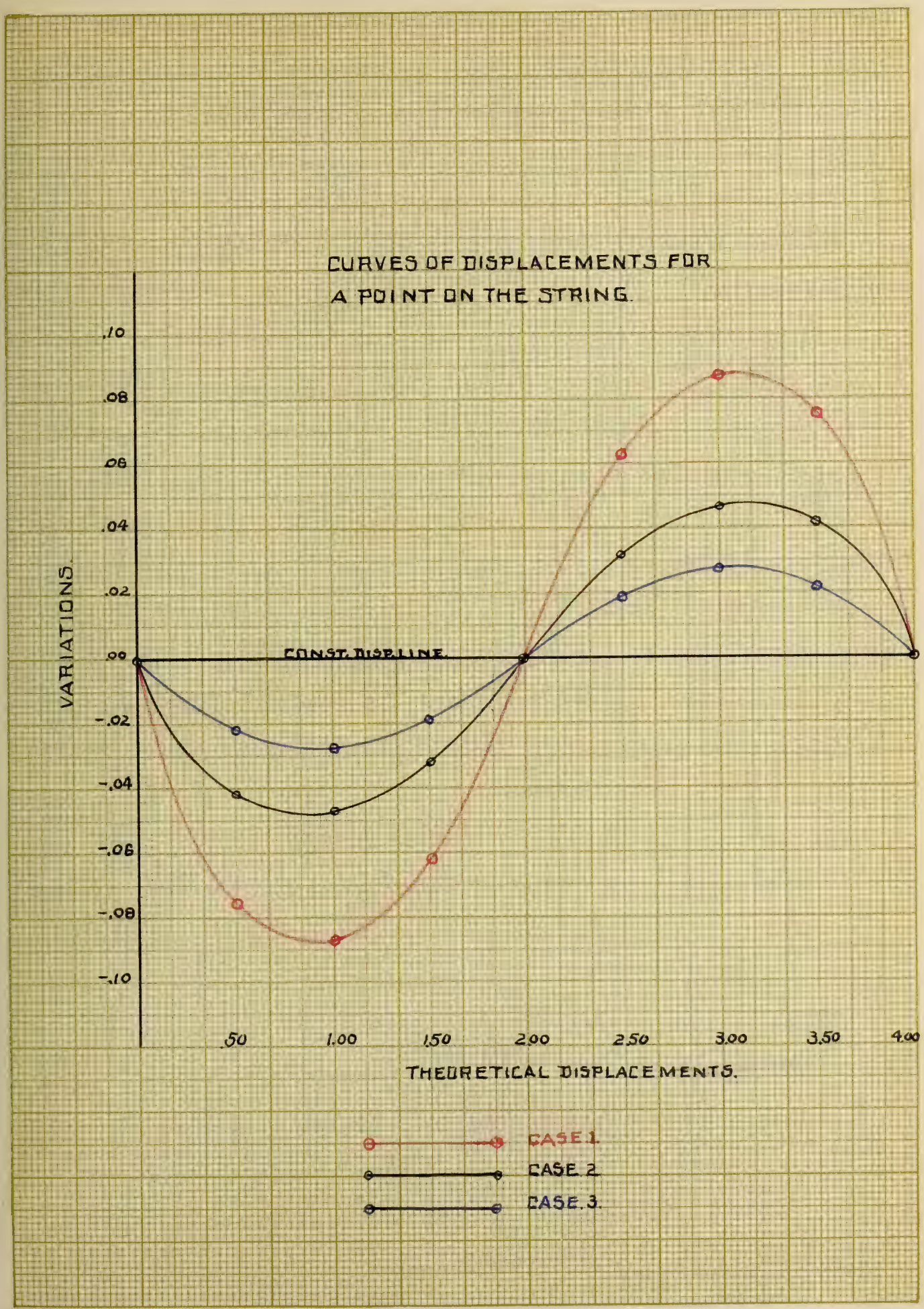

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displacement curves are just crossing the constant-displacement line, and the points where the velocity curves cross the const ratio line correspond to maximum and minimum points in the displacement curves. We see that motion number three gives the least variation and is the most accurate of the three. Owing to its large dimensions however it is not used, even though it is more accurate than number two.

On page 17 is shown a type of reducing motion that is often used. The leading dimensions are given near the diagram. In this case as in the one just previous I have assumed different conditions, and investigated the effect on the accuracy of the reduction. The link R.+ B. is made equal to the stroke one and a half times the stroke, and twice the stroke. The length of link D is varied and the effect of this variation is determined. The fixed pivot was raised and lowered, so as to cause the link D to swing always above or below the center line of the cylinder, producing quite a marked change in the results obtained from the motion. The method of solution is shown on page 8. The line a d is drawn perpendicular to the line of travel

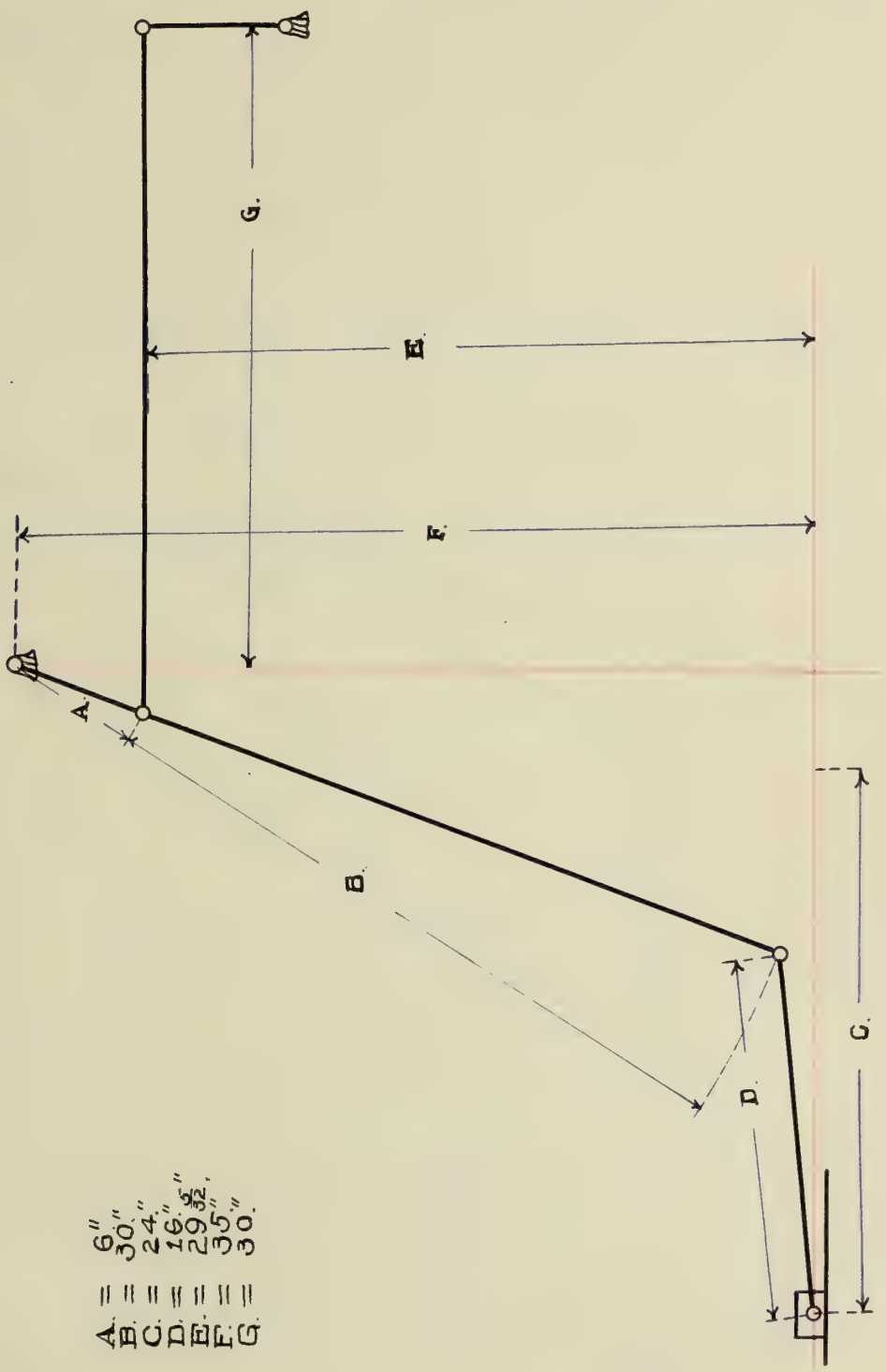
of the crosshead through the extremity of link D. Through a the line a, e' is drawn parallel to link A + B. Link D is continued until it intersects at e'. The line e' d' is then drawn parallel to the line of stroke. We then have vel. $\frac{c'}{e'} = \frac{a}{a'} \frac{b'}{d'}$ as our velocity ratio between string and crosshead. The curves shown on this page are velocity ratio curves, which I have transformed into velocity curves. such as are shown on page 14. If we examine these curves, we find that our velocity at the very start is greater than it should be, but it soon drops below the constant ratio line and begins to decrease again, then increases and near the end of the stroke decreases. We see that there is quite a large difference between the curves for A + B = C and A + B = ½ C, the later giving the better results. As between A + B = ½ C and A + B = 3 C it seems that the former is the better of the two. The velocity is more evenly distributed along the stroke. In the later case there seems to be an accumulation of velocity in the fore part of the stroke, which is not evened up until near the end.

Looking at the displacement curves, we see

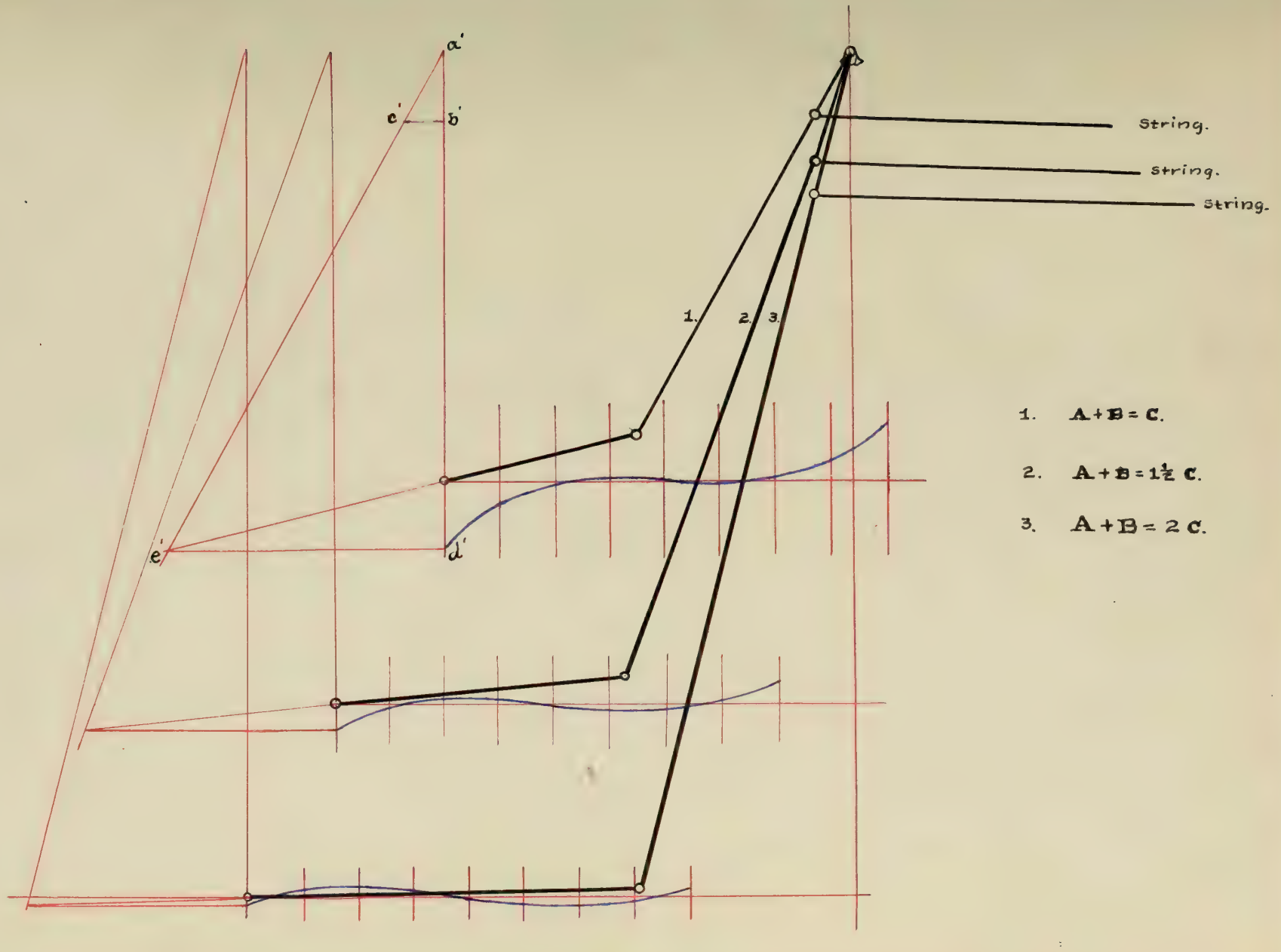
that there is a wide variation between the cases where $A + B = C$ and $A + B = \frac{1}{2} C$ the latter being much the better. The third case where $A + B = 2C$ does not seem to give as good results as where $A + B = \frac{1}{2} C$.

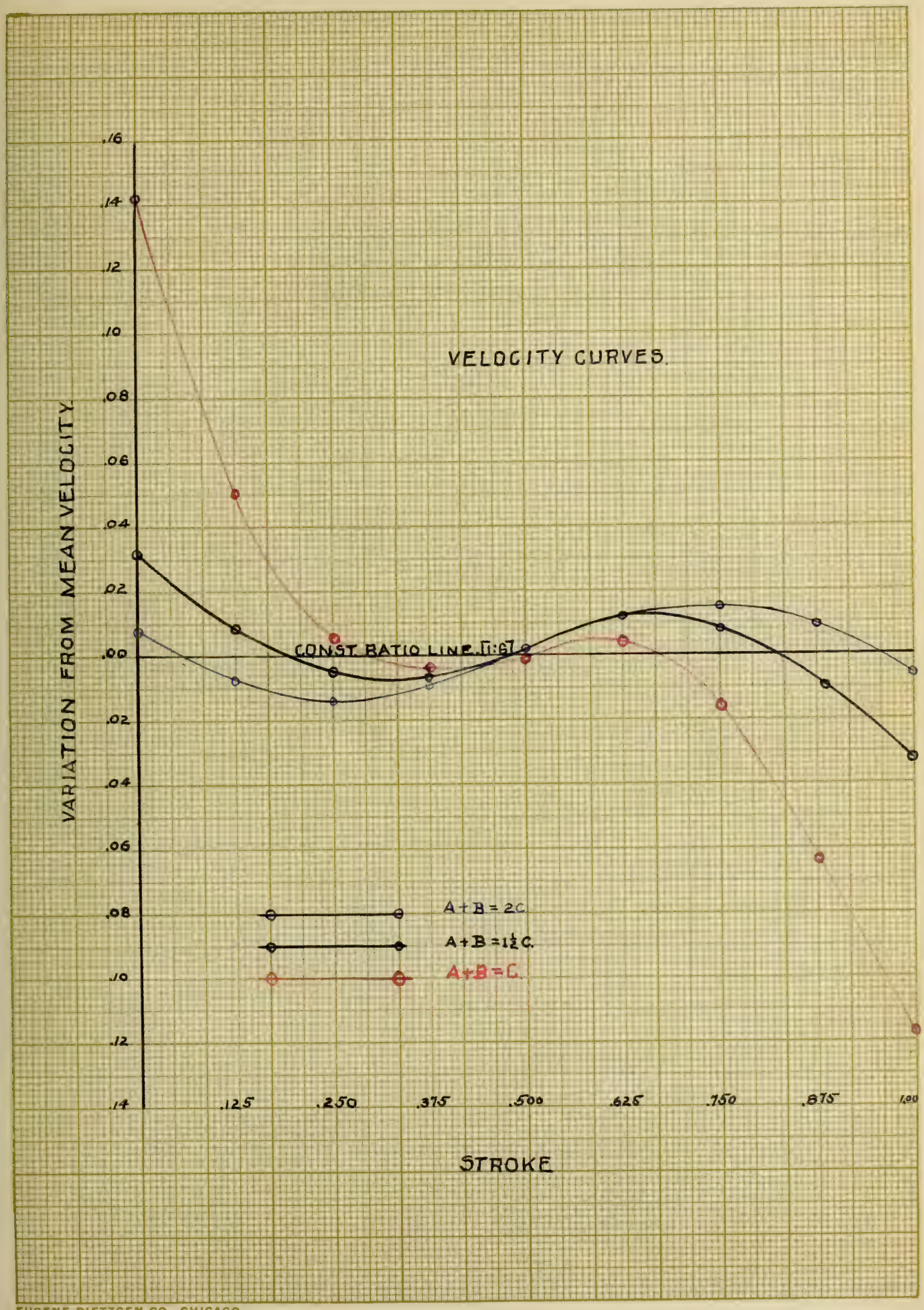
On page 21 are four other cases for investigation. In Case one we have the swinging link K always a little on the center line of the stroke. The dimensions here are the same as given on page 7. In Case 2 the link K is one half time a time and one half the time beyond the center line. In Case 3 the link K is always below the center line and in Case 4 the length of the link K is doubled.

On page 22 is a set of velocity curves corresponding to this set of conditions. We find that the best result is obtained in Case 2 where the link is made equal to $2K$ in length. It is not difficult to see that this change is sure to increase the accuracy of the mechanism. As the link increases in length approaching infinity the more nearly accurate the motion becomes. As between Case 1 and Case 3 it seems that a greater error would be produced by reducing the link K to zero



A = 6"
B = 30."
C = 24."
D = 16 25/32"
E = 29 25/32"
F = 35."
G = 30."


a'
c'
b'
e'
d'
1.
2.
3.
String.
String.
String.
1. A+B=C.
2. A+B=1½ C.
3. A+B=2 C.



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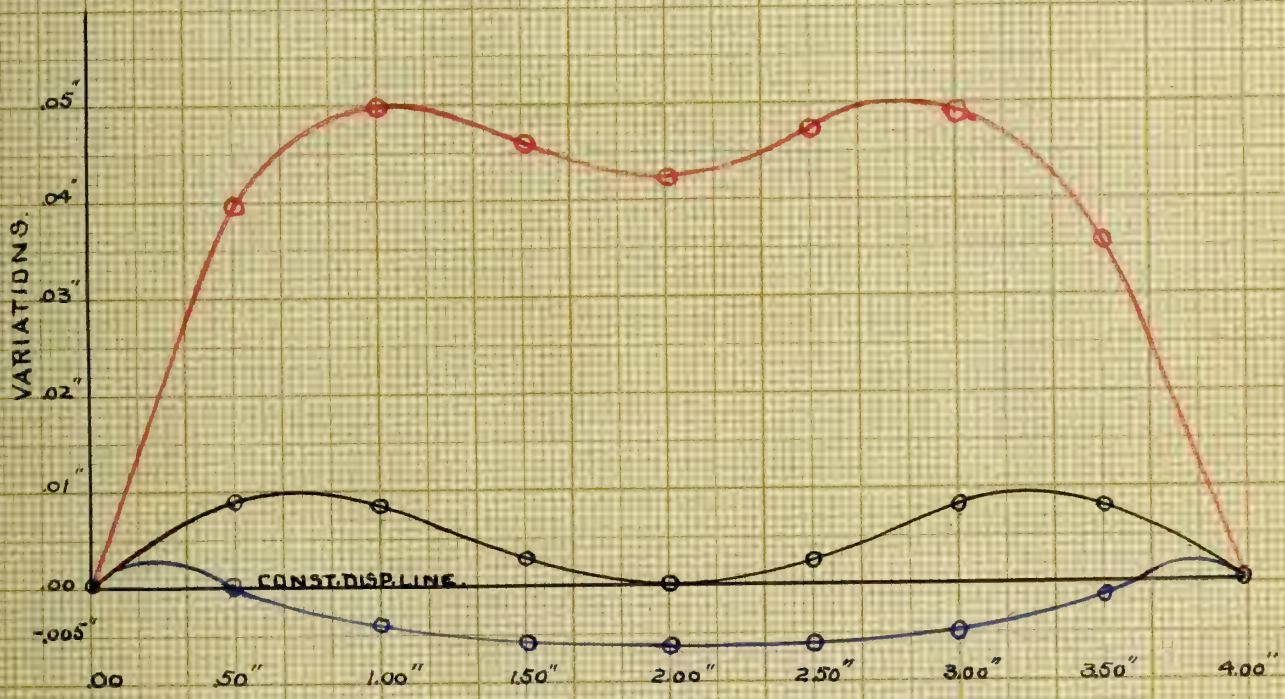
CURVES SHOWING DISPLACEMENTS OF POINT ON STRING FOR EQUAL INCREMENTS OF PISTON TRAVEL.



THEORETICAL DISPLACEMENTS.

A + B = C.
A + B = 1½ C.
A + B = 2C.

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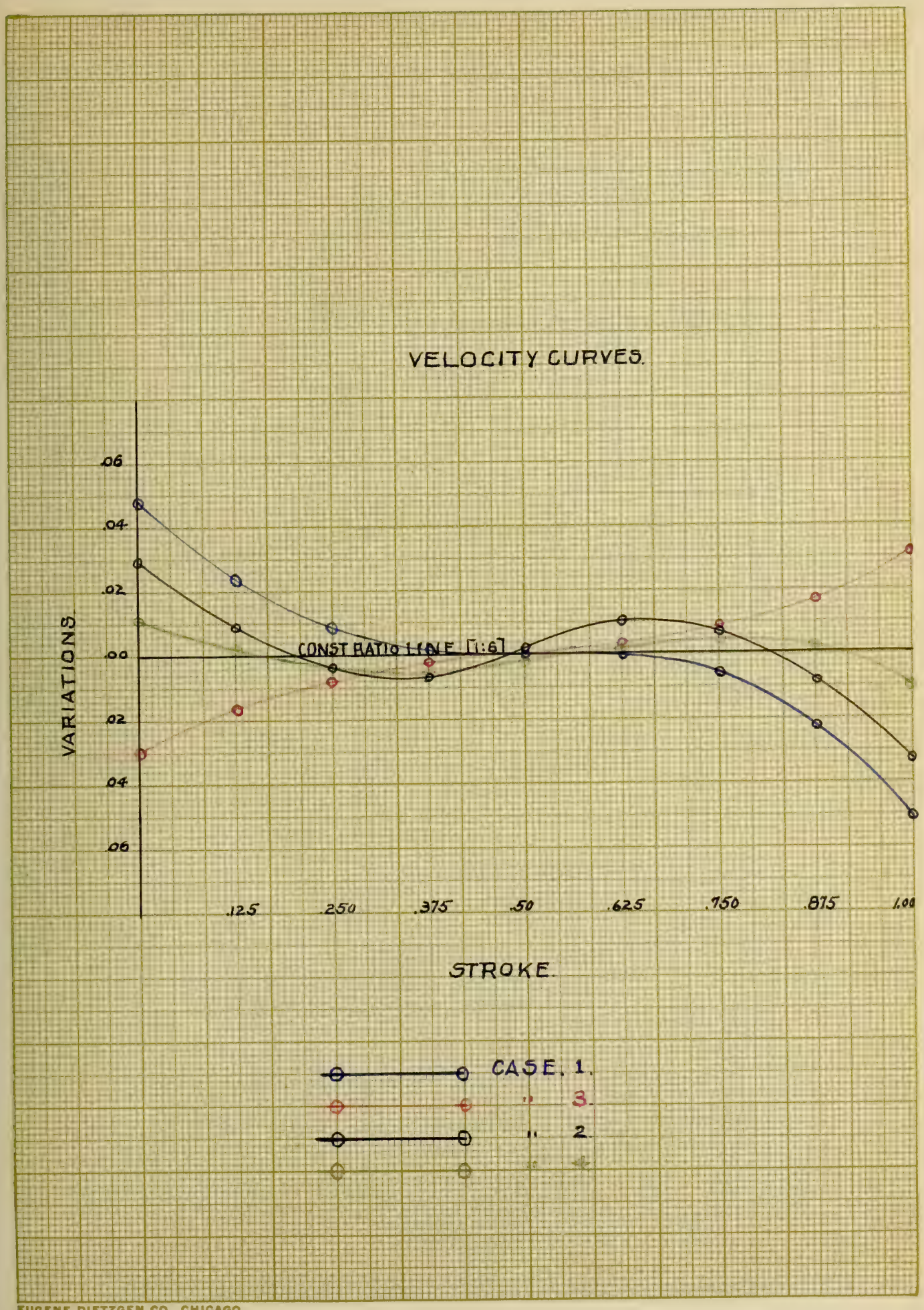
FOUR CASES

FOR

INVESTIGATION.



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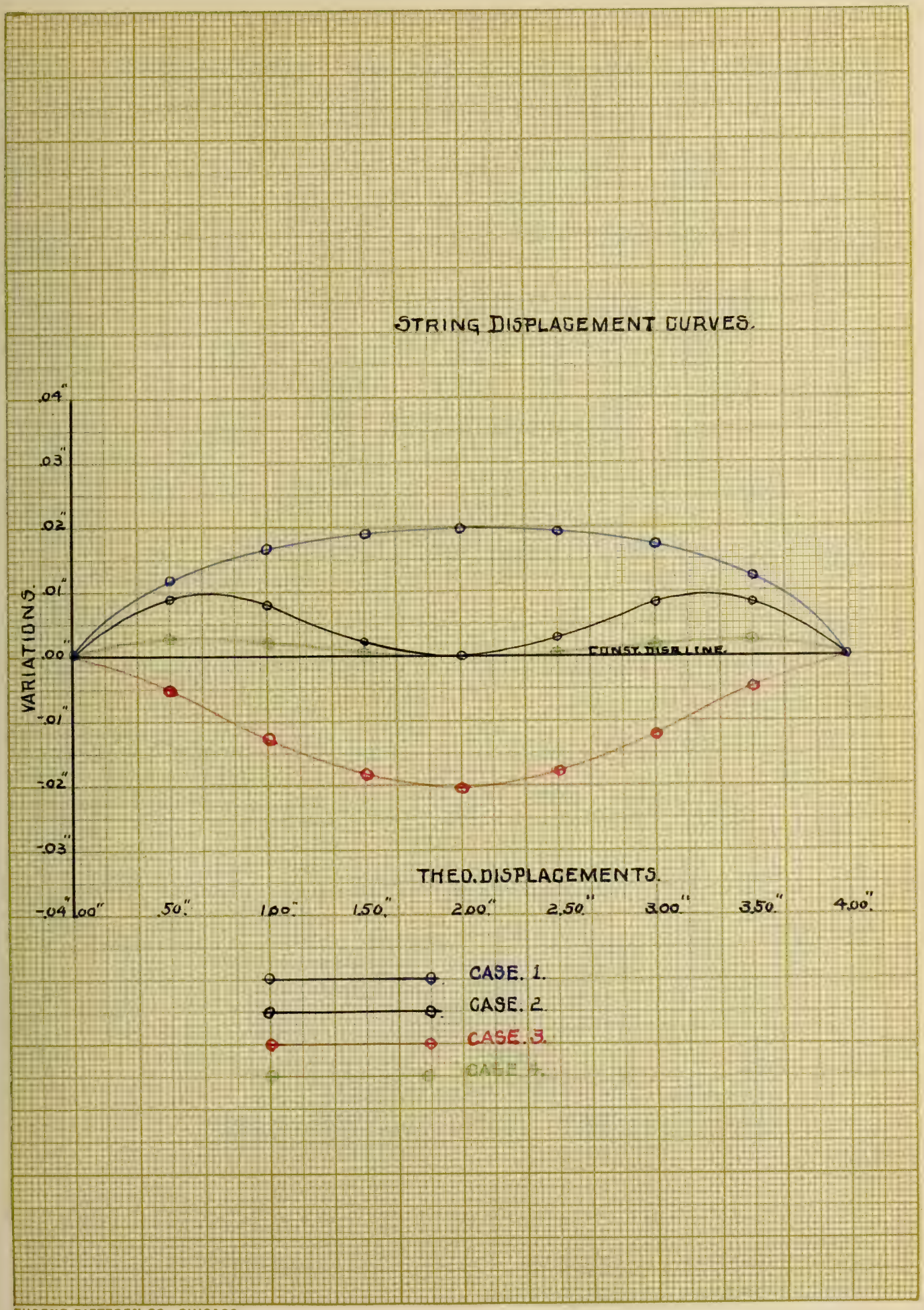

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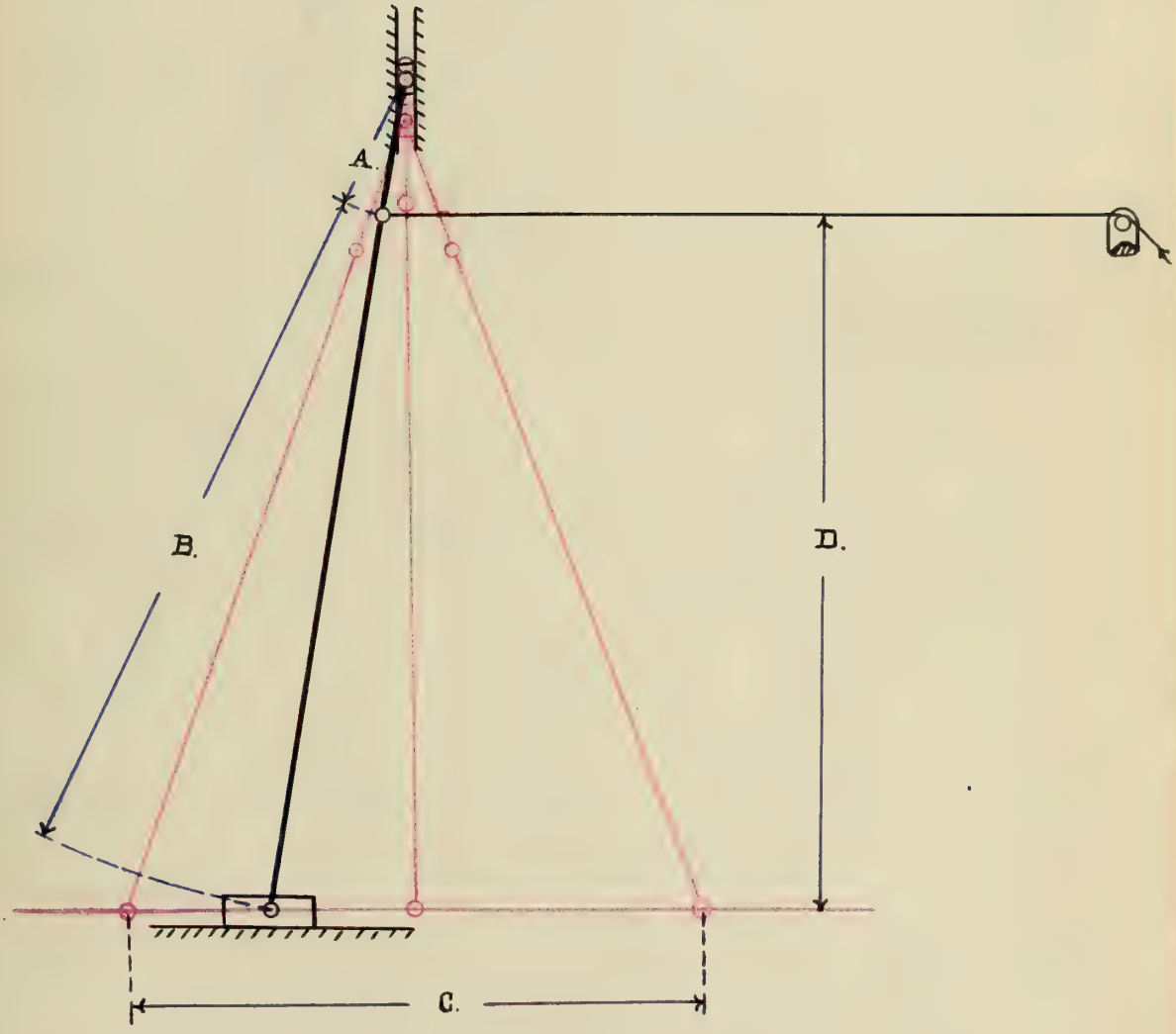
always above the center line. those always below it. Case 2 is the same as found in the former set of curves.

Examining the displacement curves we reach the same conclusions as from the velocity curves. Case 4 giving the best results and Case 2 next best of the four curves. We may decide that to get the best results from this particular motion we should have $\phi_1 = \frac{1}{2}\theta$ and to make the swinging link h as long as practicable having the link bi so located that the link h swings equally above and below the center line.

Examining the retarding motion represented on page 26 we find that it is as accurate as any of the approximate motions in the list. This type has been investigated in the same manner as in the two previous types. On page 27 is shown the three cases taken for the value $\frac{1}{2}$ Dimensions. The method of solution is also shown on this page. On page 28 is shown a set of velocity curves corresponding to the three cases. We see that the variations here is not nearly so marked as in the previous cases. The best result comes from

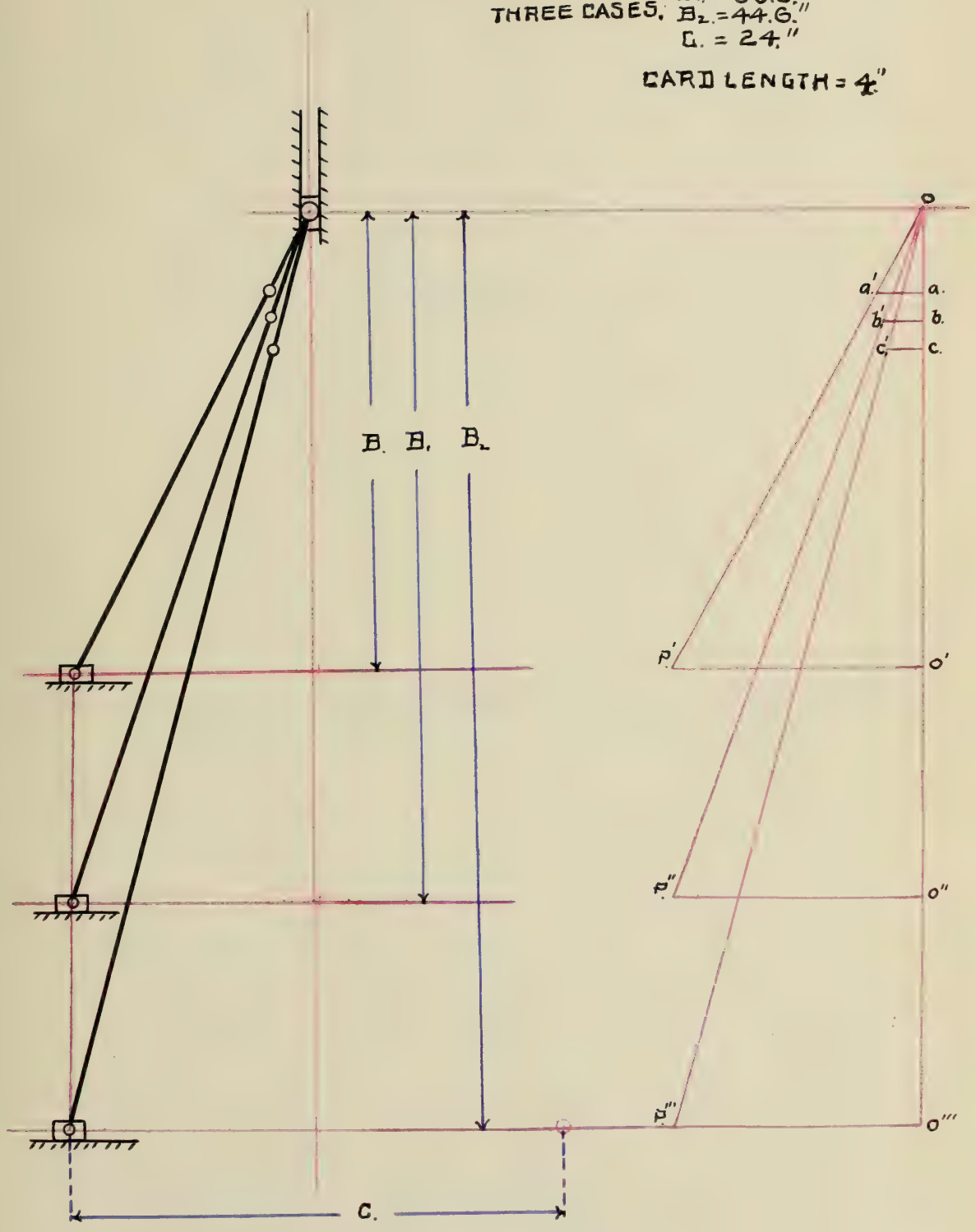
case three. and next to this Case 2, the one which is usually used. This gives fairest result. although the variation between the two cases is very small. Looking at Case 2 we see that at the beginning of the stroke the velocity is a little too great which of course means that the string is traveling faster than it should. The string displacement is then getting a head and growing greater. At which we see that the velocity curve crosses the zero velocity line and begins to grow less. At this point we see that the displacement has gone a head as much as is possible for it to do and begins to decrease. here again we note what was pointed out in the first discussion that one curve is the derivative of the other. At the beginning we have an accumulation of velocity which increases up to the first instrumentation and is represented by the small area under the curve. At this point the accumulation begins to decrease. the amount of negative accumulation being represented by the area under the zero velocity line and above the curve.

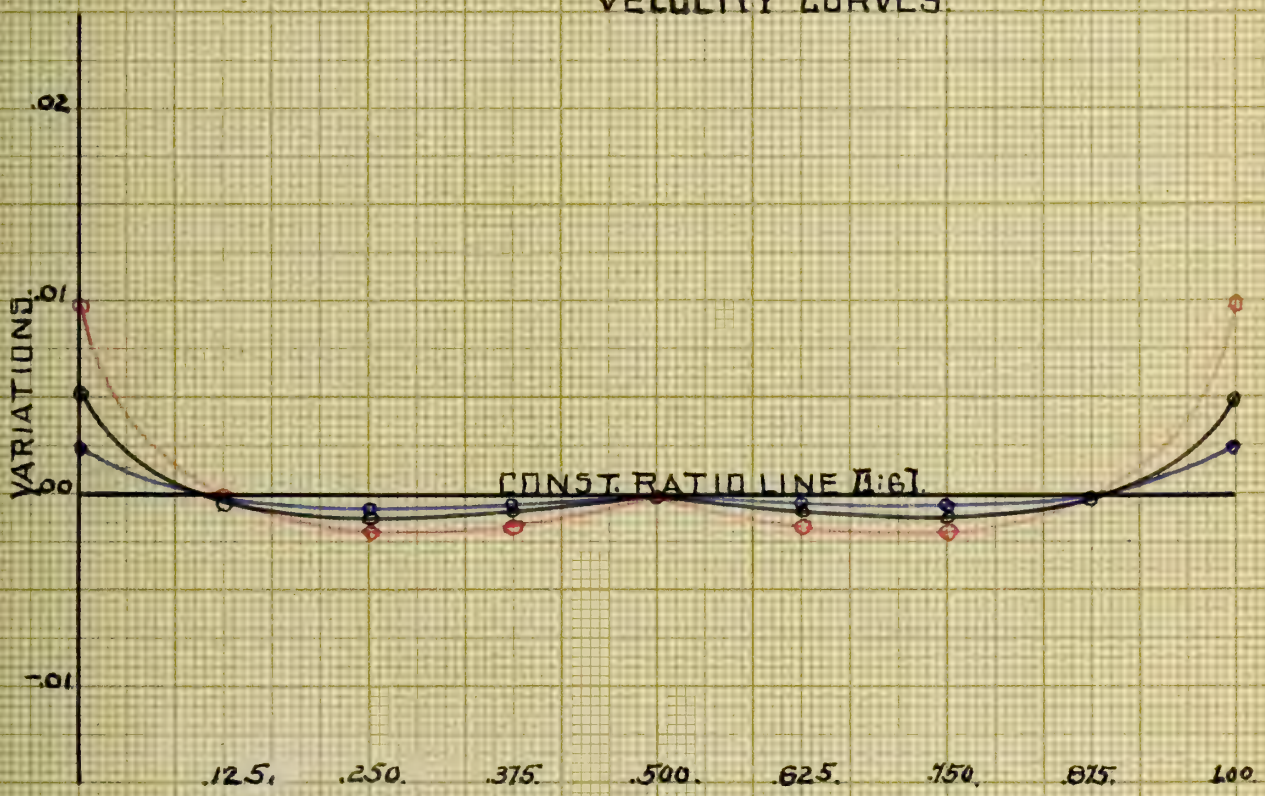
A = 6."
B. = 30."
C. = 24."
D. = 29.1"



THREE CASES. $B_0 = 22.3''$
$B_1 = 33.5''$
$B_2 = 44.6''$
$C = 24''$

CARD LENGTH = 4"





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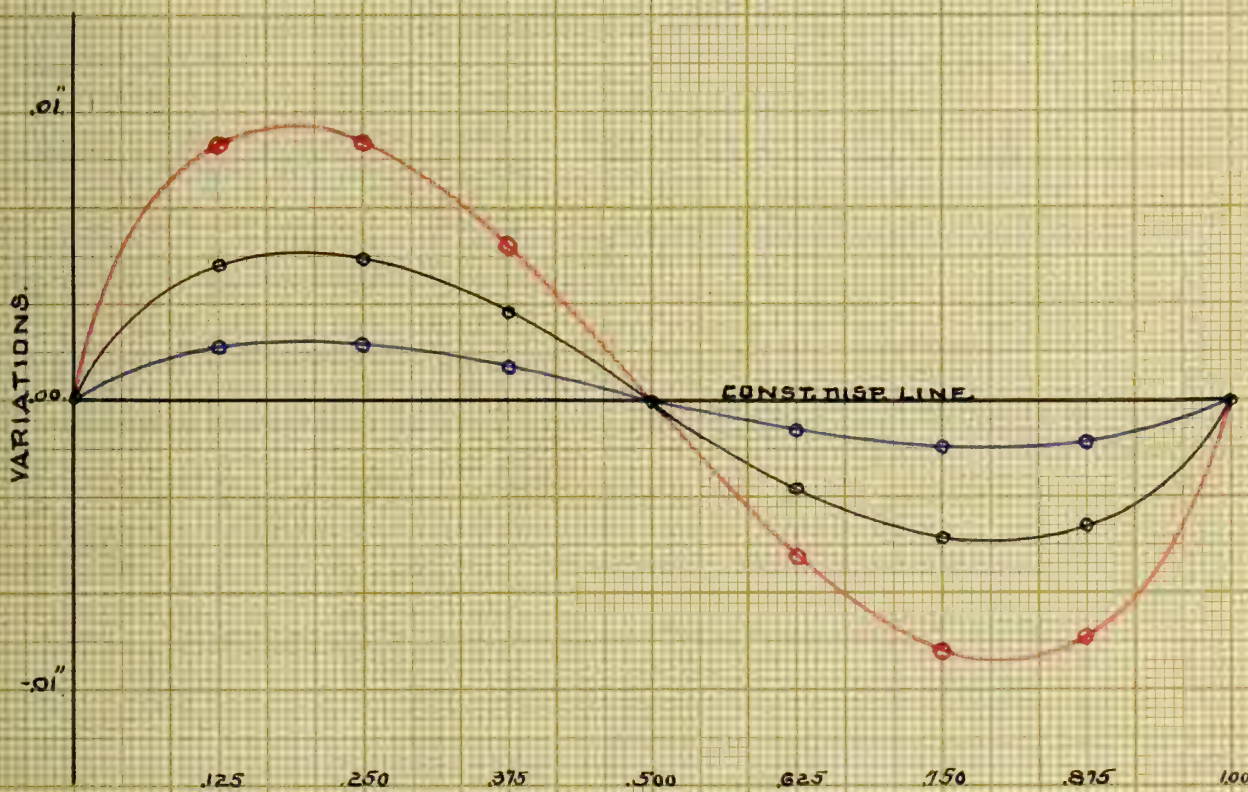
DISPLACEMENT CURVES.



.125	.250	.375	.500	.625	.750	.875	1.00
STROKE.							
.50"	1.00"	1.50"	2.00"	2.50"	3.00"	3.50"	4.00"

Theo. Disp't's.

CASE 1.
CASE 2.
CASE 3.

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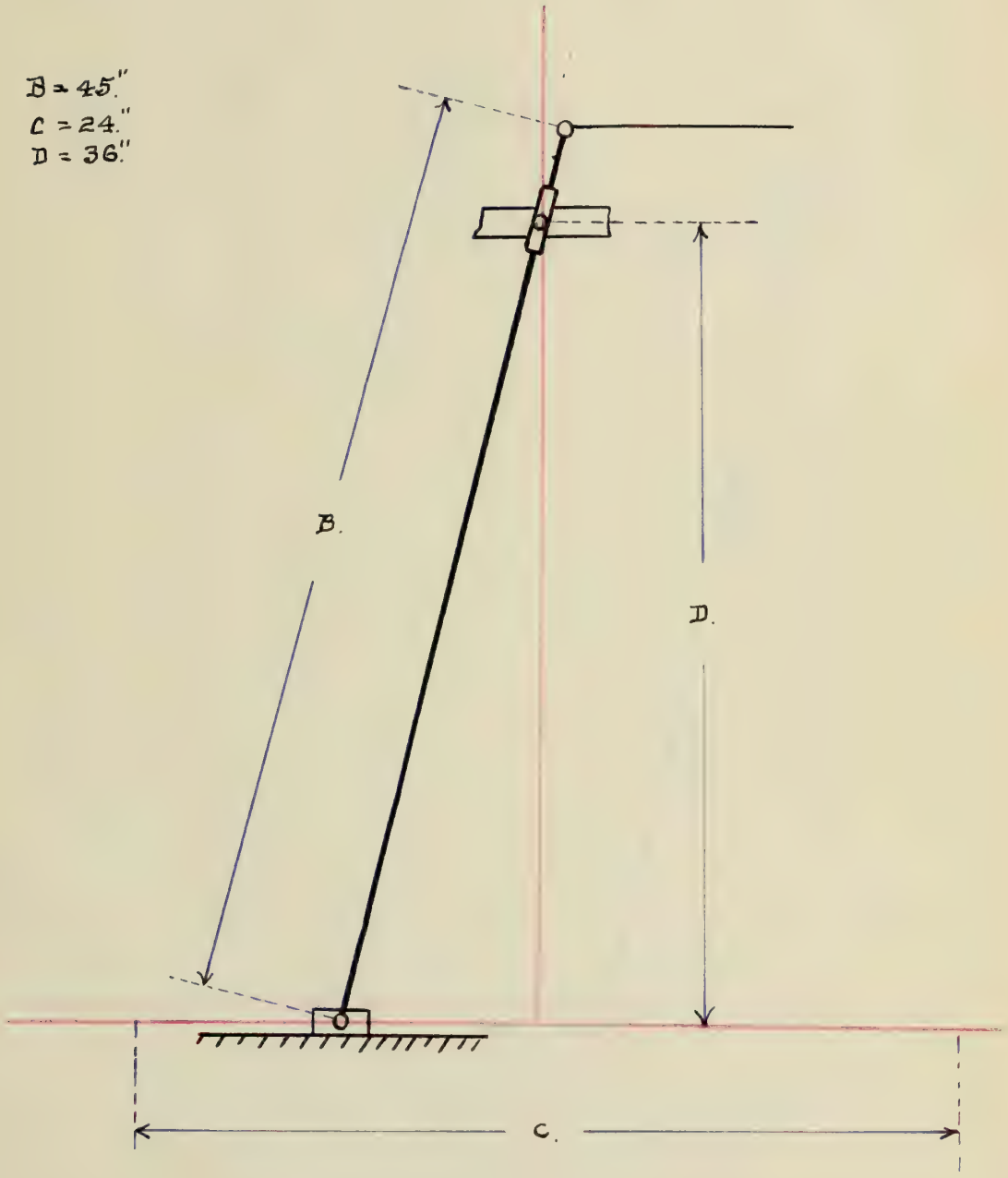
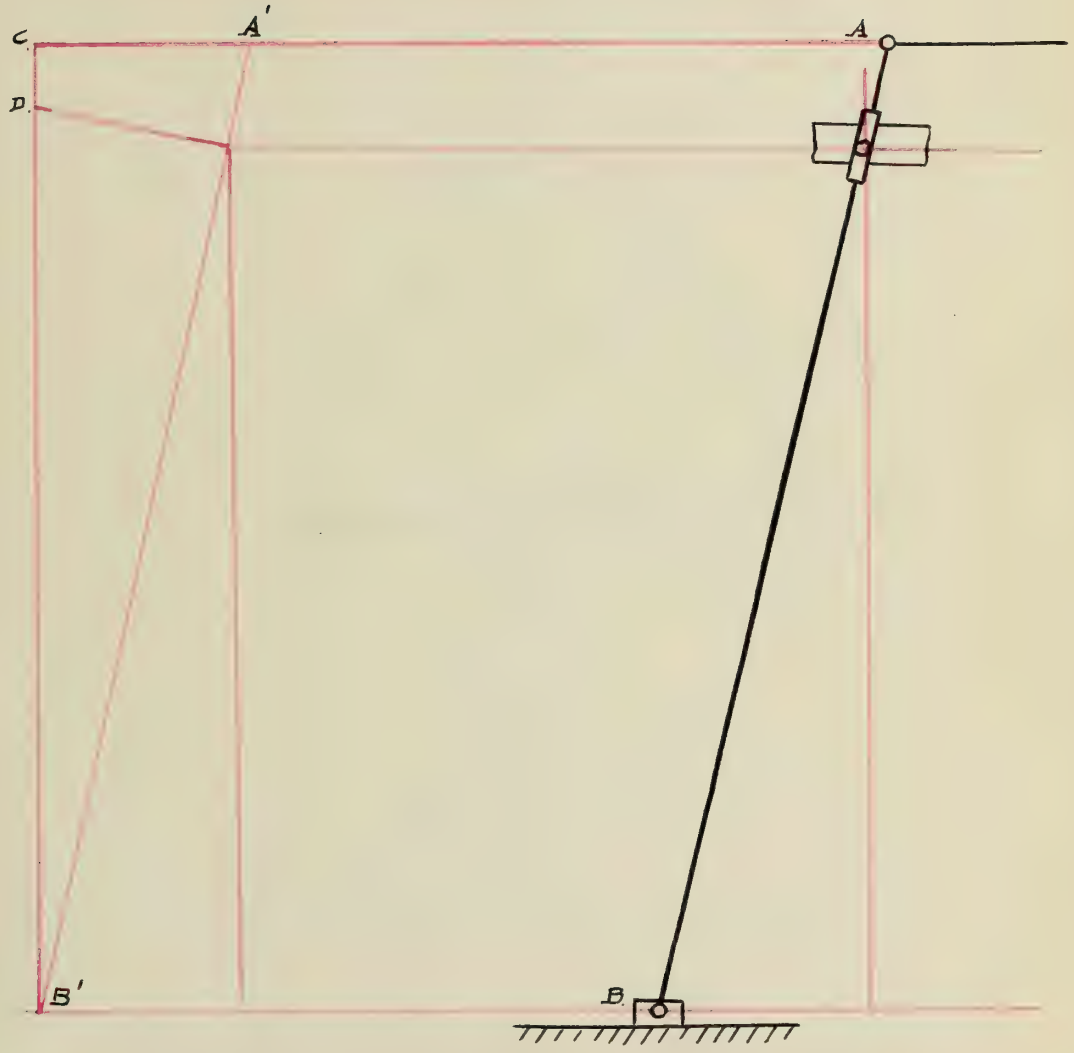
These two areas must be equal, one being positive and the other negative. We can see that at the center of the stroke the velocity ratio has become 1:6.

Just here we have an error setting in at the stroke. We have an error until within ⅛ of the end of the stroke. From here on the error would be slightly reduced if the cutoff were at ¾ stroke the error would be less. At ½ stroke it would still be less. Where the cutoff is late and the load on the engine is great we get a much larger area on the card and consequently the percentage of error produced by the valve becomes small. Compound work where we have an early cutoff and small card area.

The last motion investigated is that shown on page 31. This is a very inaccurate type as one can readily see and could scarcely be used without introducing great error into the results. The principal dimensions are given on the above type and the method of solution is shown on page 32. I have investigated only the one case, not considering it worth while to spend more time on such an inaccurate type.

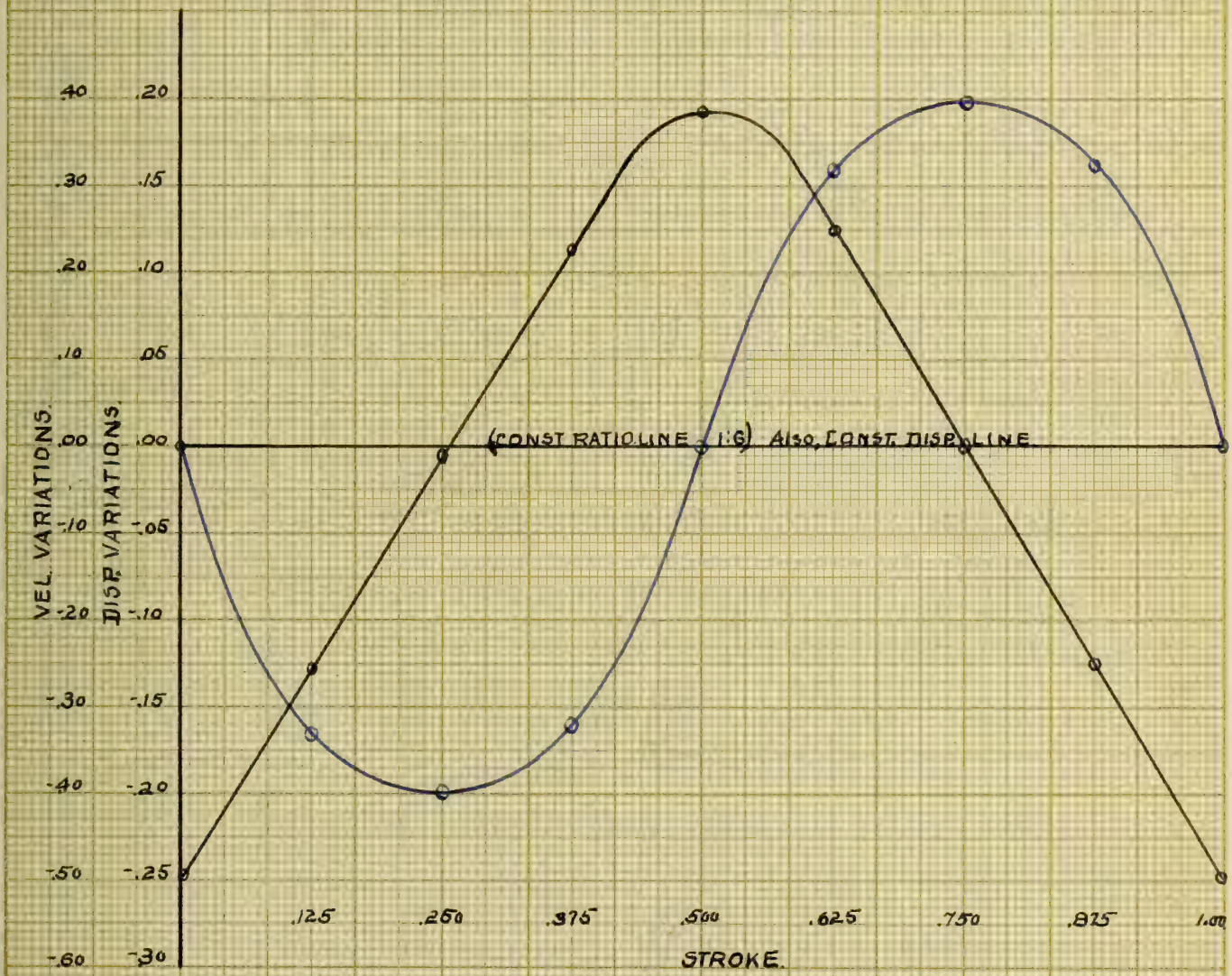
B = 45."
C = 24."
D = 36."





$$VEL._{\frac{A}{B}} = \frac{CD.}{DB'.}$$

VELOCITY AND DISPLACEMENT CURVES.



DISPLACEMENT CURVE.

VELOCITY CURVE.

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Let us look at the velocity and displacement curves on page 33. We see here a wide variation in values. The velocity is small in the first half of the stroke. At ¼ stroke the velocity curve crosses the constant ratio line. Here it is just equal to the constant ratio 1:6. It continues to increase up to a maximum at the center and then decreases. We see that it begins very slow, increases to a maximum and then drops to a minimum again at the end of the stroke. The displacement curve presents wide variations. It is a maximum when the velocity curve crosses the constant ratio line. At one ¼ stroke the displacement of the string is ¾ of inch and at ⅛ stroke 34/100 of an inch. They should be one inch and ½ inch respectively. Hence we see the inaccuracy of this motion.

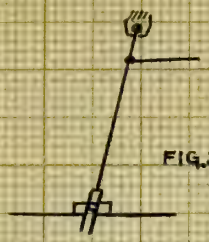
The velocity and displacement curves from the cases investigated have been plotted on two sheets for comparison. There are a set of velocity comparison curves and a set of displacement comparison curves. These are to be found on pages 37 & 36. The velocity curves have been drawn to the same scale with the exception of the last

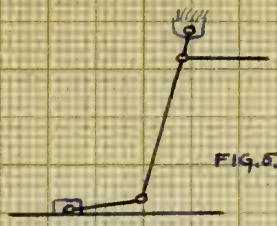
motion investigated. The displacement curves are all drawn to the same scale. By an inspection of these curves we can easily decide as to the relative accuracies of the motions which they represent.

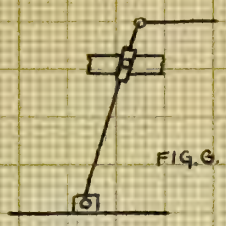
The curve of velocity and displacement drawn in red is undoubtedly the best of the set and is that given by the motion shown in figure 13. The next best are the ones drawn in blue which are given by the motion shown in figure 5. This curve represents the motion with link E equal to 16 inches. If E were made longer say 32 inches the curve would present much as regulation as has already been demonstrated. The curve drawn in black represents the next in accuracy. Last and least accurate is the motion shown in figure 6 and represented by the dotted curves.

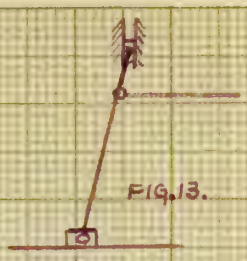
We may then easily rate the motions in regard to their accuracy as follows,

Figure 13 first.
" 5 second.
" 3 third.
" 6 fourth.









VELOCITY COMPARISON CURVES.

FIG. 3.
FIG. 5.
FIG. 6.
FIG. 13.

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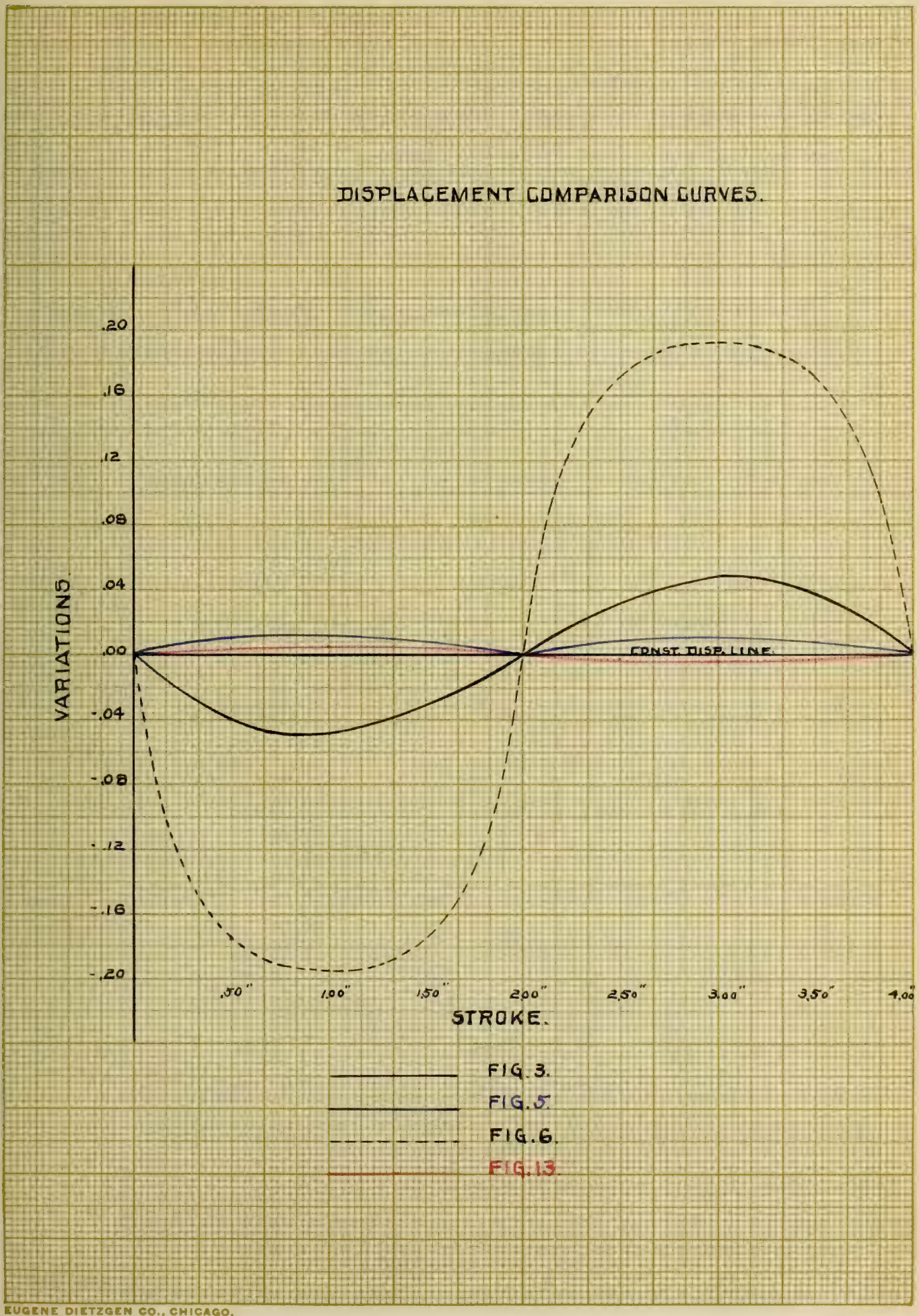

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After completing the investigations just discribed. an attempt was made to compare an approximate motion with one known to be correct by means of actual experiments on an engine. On page 39 is a diagramatic sketch showing the general arrangement of the apparatus. Two indicators A. & B. were so arranged as to take cards from one end of an engine cylinder simultaneously. The cords of the indicators were first connected to the correct motion and a series of ten cards from each motion taken. Their areas were planimetered and compared and in this way the two indicators were calibrated. Ten more cards were then taken from each indicator. using each motion, their areas determined and the percentage of error found thus giving a direct check on the two riggings. Care was taken to avoid any lost motion that might occur in the mechanisms. and the cords were kept nearly horizontal.

On page 41 are two cards. first separate and then combined representative of the ten cards taken from each indicator for calibrating purposes. The areas of the twenty cards taken are as shown in

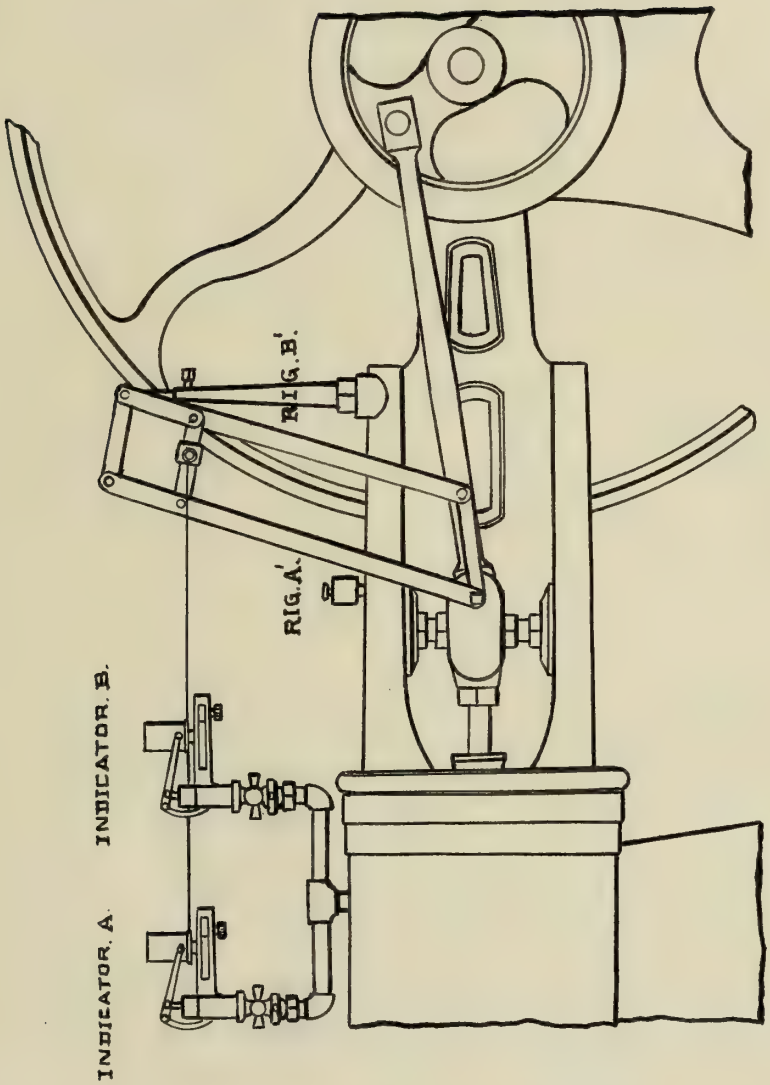

FIG. 17.

the following table.

Card No.	Indicator A.	Indicator B.	Difference.	% Variation.
1	7.49	7.43	.06	.80
2	7.82	7.76	.06	.76
3	6.97	6.92	.05	.71
4	6.24	6.19	.05	.80
5	5.38	5.33	.05	.93
6	5.93	5.87	.04	.67
7	6.32	6.27	.05	.79
8	7.10	7.04	.06	.84
9	7.28	7.23	.05	.68
10	6.31	6.27	.04	.64
Mean % Variation = .76 %				

Connecting a card to each rigging. Ten cards with the areas shown below were taken. Indicator A was connected to the approximate motion.

Card No.	Indicator A.	Indicator B.	Diff.	Diff. due to Indicator	% Error due to Motion.
1	3.99	3.84	.15	.03	3.1
2	4.02	3.90	.12	.03	2.3
3	3.60	3.46	.14	.02	4.7
4	3.84	3.68	.16	.03	3.4
5	3.91	3.80	.11	.03	2.1
6	4.12	3.96	.16	.03	3.2
7	4.22	4.10	.12	.03	2.2
8	4.00	3.86	.14	.03	2.8
9	3.78	3.63	.15	.03	3.3
10	3.61	3.49	12	.02	2.8
Mean % Variation due to Motion = 2.99					

Another set of twenty cards were taken with a longer cut-off and larger

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BOILER PRES.

R. P. M.

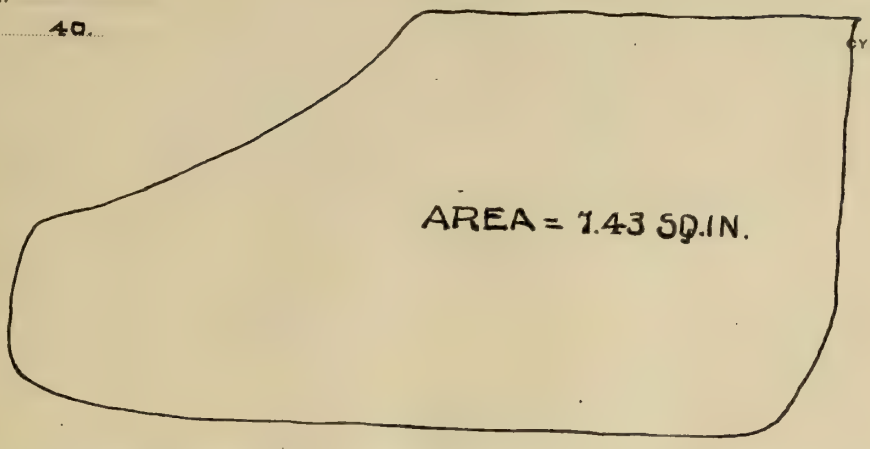
SCALE 40.

CARD NO.

END COR.

CYLINDER

Bachelder 1¾-inch Drum



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BOILER PRES.

R. P. M.

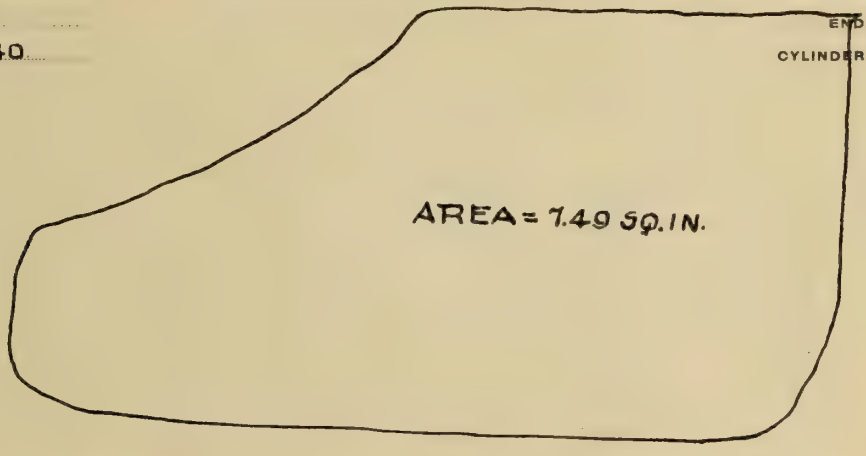
SCALE 40

CARD NO.

END APPROX.

CYLINDER

Bachelder 1¾-inch Drum



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BOILER PRES.

R. P. M.

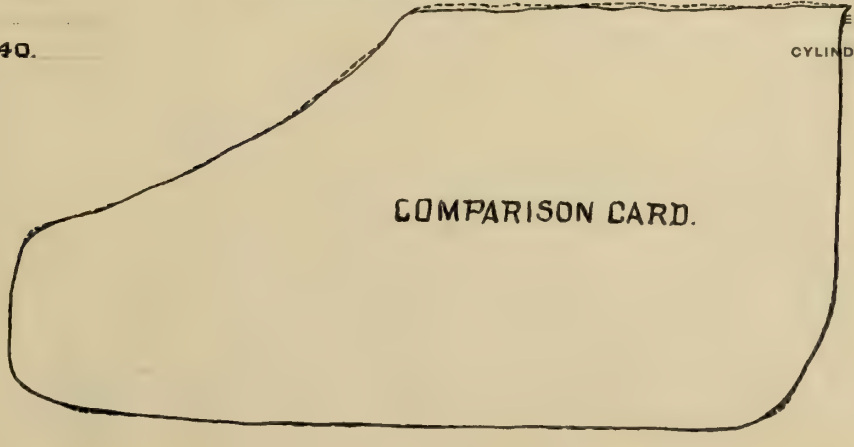
SCALE 40.

CARD NO.

END

CYLINDER

Bachelder 1¾-inch Drum



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BOILER PRES. .....

R. P. M. .....

SCALE 40.

CARD NO. .....

END COR.

CYLINDER .....

Bachelder 1¾-inch Drum

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CARD NO. .....

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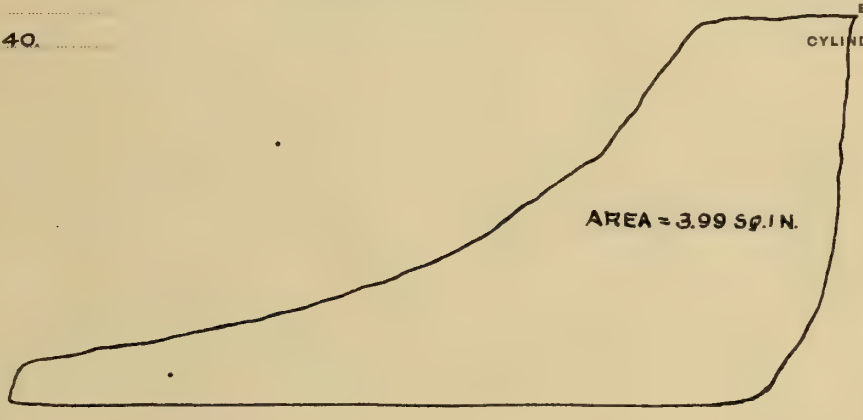
CYLINDER .....

Bachelder 1¾-inch Drum



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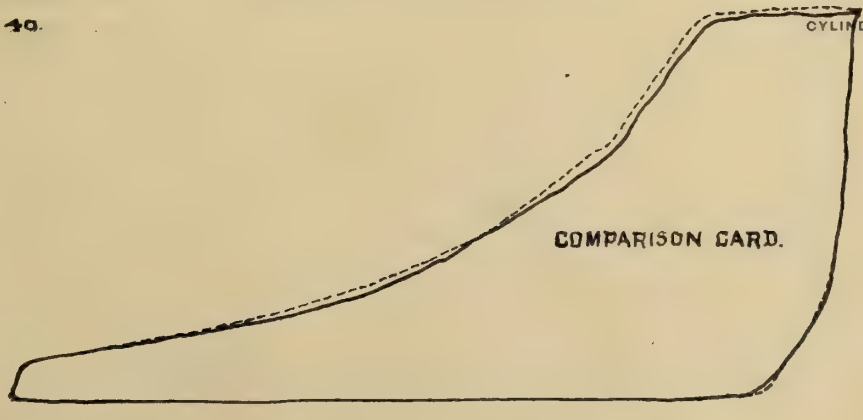
SCALE 40.

CARD NO. .....

END

CYLINDER

Bachelder 1¾-inch Drum



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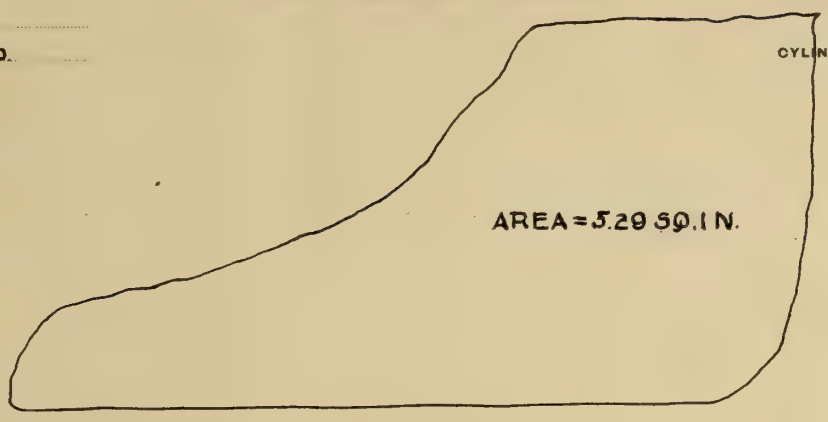
Bachelder 1¾-inch Drum



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Bachelder 1¾-inch Drum

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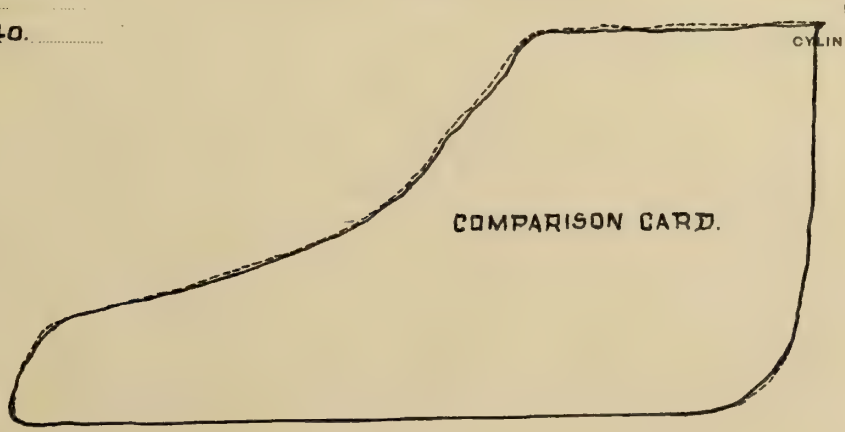

card Area. The results from these are as shown in the table below.

Card No.	Ind. A.	Ind. B.	Diff.	Diff due to Indicator	% Error due to Motion.
1	5.42	5.29	.13	.04	1.7
2	5.31	5.20	.12	.04	1.5
3	4.90	4.81	.09	.04	1.0
4	4.76	4.65	.11	.03	1.6
5	4.97	4.87	.10	.04	1.2
6.	5.12	5.00	.12	.04	1.6
7	5.22	5.08	.14	.04	1.8
8	5.31	5.20	.11	.04	1.3
9	5.28	5.16	.12	.04	1.5
10	5.02	4.88	.14	.03	2.2
—	—	—	—	—	—
Mean % Error Due to Motion = 1.54.					

Discussion of Experiments.

Let us see what conclusion we are to come to from the experiments performed. From the first cards taken we find upon calibrating the two indicators as formerly discribed that there is a variation of .7% . Indicator A gives .7% to great a result. Now when we connect indicator A with the approximate motion and B with the accurate motion we find after deducting the error due to the indicator variation that the results obtained by A are still 2.99% greater than those obtained from B. This error we charge to the approximate

motion. It will be noted that the cutoff in these cases was at a point 3/8 stroke. In the next set of cards the load was increased until cutoff and R. place at a point 1/3 stroke. Proceeding as before we find that now the error in this case equal to 1.54%, much less than before. This is due to the later cutoff and larger card area. The later the cutoff the less the error due to the motion becomes and the larger card area the less the same error would amount to in any case.

Let us refer for a moment to the displacement curve given on page 20 representing the above into this card. If the cut off is at 3/8 stroke we can see from the nature of the curve that the error is going to be greater than at 1/3 stroke.

Suppose the engine cutoff at the beginning of the stroke, we then have an error throughout the entire stroke due to the motion. If it is to cut off at one half stroke we have an error through the remaining half of the stroke due to the unequal displacements of the string. The increasing area of the card and decreasing area of the motion curve

us to come to the conclusion as I have heretofore stated that where the load is great and the cut off delayed the error due to the use of the approximate motion becomes very small or we may say that the percentage of error decreases with the load on the engine.

It seems that the results of these experiments cannot be far from right. They were performed with a great deal of care and as we have seen they agree quite well with the displacement curve already found so far as the error in the motion is concerned.

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